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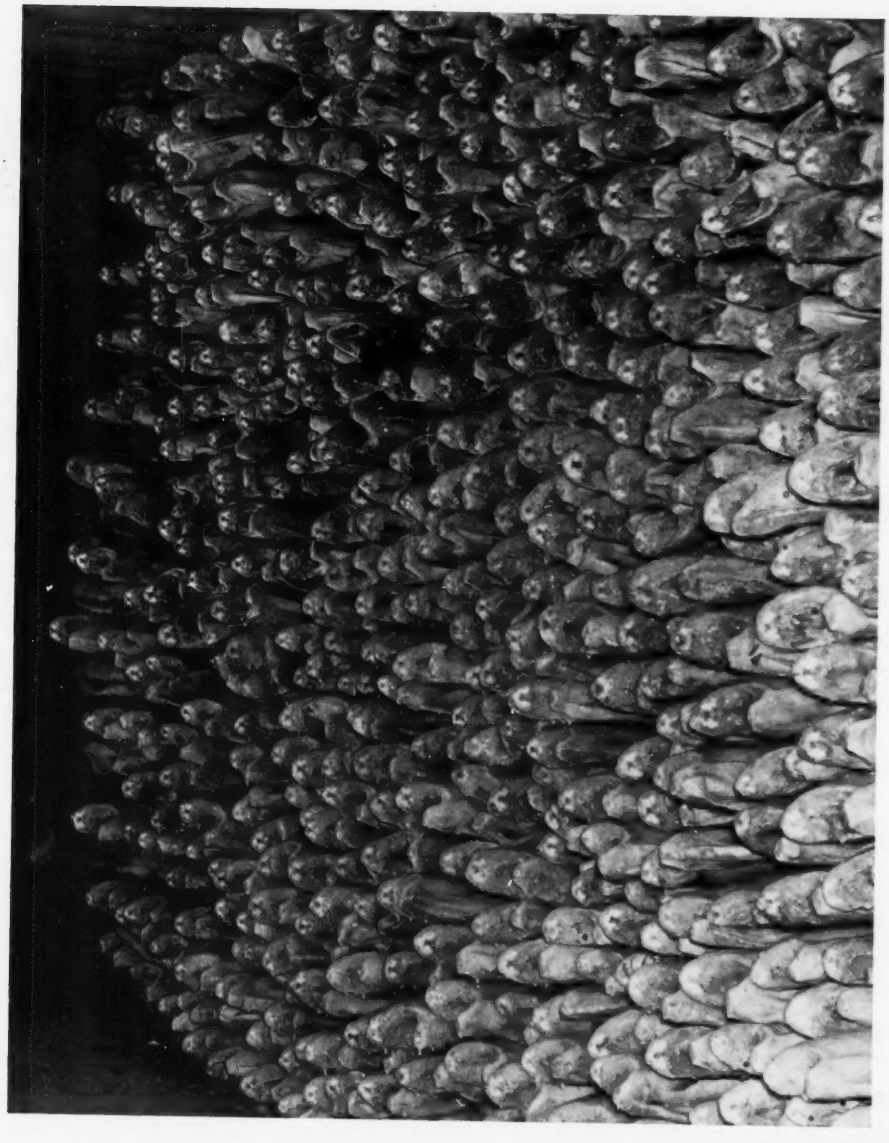
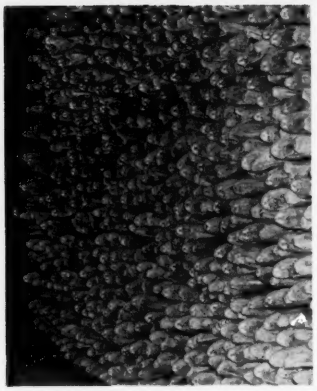


Low Temperature Preservation of Seafoods

Marine Fisheries REVIEW



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Low Temperature Preservation of Seafoods: A Review

LOUIS J. RONSIVALLI and DANIEL W. BAKER II

ABSTRACT—Cooling seafoods is among the most effective methods for preserving their quality. From a choice of refrigerants, we can cool them to just above the point of freezing (chilling); when freezing is undesirable, we can cool seafoods to a state in which they are partially frozen (superchilling) which extends the shelf life by 100 percent or less but still does not freeze them in the usual sense; or we can freeze them solid (freezing) and extend their shelf life for months and even years, when the temperature is low enough. This paper describes the common refrigerants including ice, brine, ammonia, fluorocarbons, cryogenic gases and liquids, chilled seawater, and refrigerated seawater. Conventional processes and equipment for freezing seafoods, including gas and liquid mechanical refrigeration systems, are described, as are less conventional or theoretical systems, including dehydrocooling and high-altitude freezing.

Introduction

Because of their ease of digestibility and the nature of the microbial and systemic enzymes that cause their spoilage, seafoods are among the most perishable of foods (Bramsnaes, 1957). The seafood spoilage rate depends on the speed with which the chemical reactions that cause their spoilage proceed. As is generally true for chemical reactions, the speed with which fish spoilage proceeds depends on the temperature of the system. The relationship between the rate of fish spoilage and temperatures has been widely observed and reported, and shelf life prediction devices have been constructed from some of these studies (Spencer and Baines, 1964; James and Olley, 1971; Charm et al., 1972; and Ronsivalli et al., 1973).

Although we are addressing the direct relationship between the spoilage of fish and the reaction rates of the enzymes, we do not want to ignore the fact that these enzymes are produced from bacteria and that the metabolic and numerical growth rates of bacteria are also enhanced by an increase in temperature (within limits). For example, while the generation time for *Pseudomonas fragi,* a common fish spoilage bacterium is about 12 hours at 32 °F (0 °C), it is only about 2 hours at 55 °F (12.9 °C) (Duncan and Nickerson, 1961). Obviously, the rate of production of bacterial enzymes is influenced by the metabolic rates and number of bacteria. While the roles of bacterial enzymes and bacterial numbers in fish spoilage are important and relevant to the subject of this paper, no further discussion will be made of these here. Instead, the reader is referred to Ronsivalli and Charm (1975), where a more detailed discussion already exists and additional references are given.

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There is little doubt that the storage temperature is the most important variable influencing the spoilage of seafoods; and to optimize the preservative effect of lowering their temperature, it is helpful to understand the principles at work as well as the relationship between the temperature of a given seafood and its shelf life. Much work has been done to combine low temperature with other treatments such as the use of bacteriostats and bactericides (Windsor and Thomas, 1974), and some work has been done in vacuum (Licciardello et al., 1967) and modified-gas packaging (Veranth and Robe, 1979), but this discussion is limited only to the control of temperature.

For prolonging the quality of fish by simply controlling the temperature, the best results are obtained when the temperature control is applied immediately after the fish are caught. This is because the quality of fish is highest at point of catch and it undergoes irreversible quality losses with time at rates that are directly related to temperature.

Three categories of temperature control can be applied: Chilling, superchilling, and freezing. These control quality in somewhat different ways. The first category of temperature control is chilling. It is in the wet range of temperatures (where no freezing of the fish is desired). The chief control imposed by the temperature in this case is that it slows down the rates of the reproduction, growth, and metabolism of spoilage bacteria

and the reaction rates of the bacterial enzymes. It slows the rate of enzymic spoilage simply because, as we stated earlier, spoilage involves chemical reactions whose rates are proportional to the temperature.

Superchilling, the second category, is in the narrow temperature range from 26.6° to 30.2 °F (from -3.0° to -1.0 °C). In this range there is some freezing of the water in the fish tissues, and this is noticeable when an attempt to bend the fish is made. If the temperature is lower than this range, the fish will be frozen solid. If the temperature is above this range, there will be no freezing at all. The principle by which superchilling works is simply that the lowered temperature further slows the microbial metabolism and spoilage reaction rates. The formation of some ice also creates pockets of immobility insofar as bacterial activity is concerned.

In the third category of temperature control, freezing (0°F or -17.8 °C, or below), the product is frozen solid since most of its water is transformed to ice, and bacteria are completely immobilized. This is precisely the principle by which freezing protects fish quality. However, although freezing provides protection from microbial spoilage, other spoilage vectors such as oxygen and enzyme activity have to be controlled.

Chilling

Like other perishable foods, seafoods retain their initial quality for long periods when they are properly packaged and held properly frozen. However, there is a relatively high demand for fresh[1] (unfrozen) seafoods which command a significantly higher price at retail than frozen seafoods. The reason for the difference in price between fresh and frozen seafoods is attributed to the widely accepted belief that the quality of fresh seafoods is superior and much higher than the quality of frozen seafoods. Whether or not this notion is accurate, it does exist. Because of the high value of fresh seafoods and because of their relatively high rate of perishability, there is an economic reason to maximize their shelf life and to minimize the chance that their quality will deteriorate to the point that they lose their commercial value.

One of the best methods known for preserving the quality of fresh seafoods is to surround them with flaked or crushed ice, because this provides a quick way to bring their temperature to just above freezing.

Use of Ice

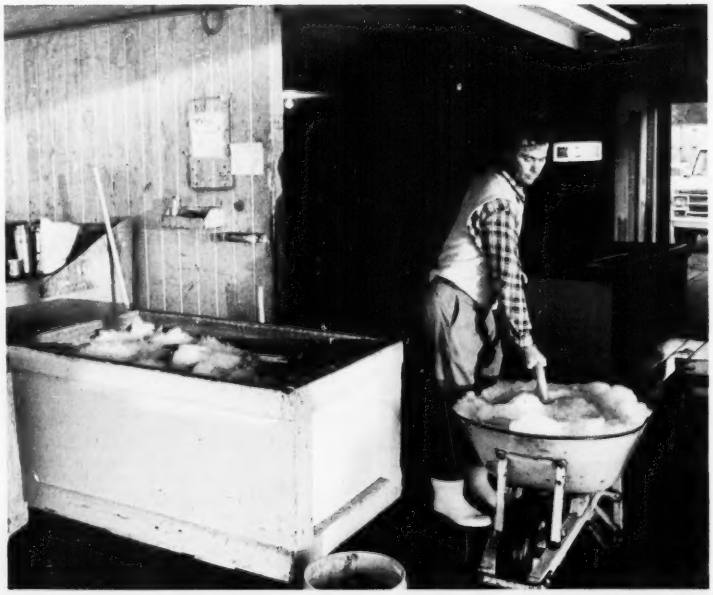
The preservation of the quality of seafoods by chilling them with ice was practiced as early as 1838 aboard New England trawlers. The principle employed was not different from that of the old domestic ice box: The ice was held in one compartment, the food was held in another, and both compartments were enclosed in a cabinet which served to keep the system separated from the environment. In fishing vessels, ice was kept in one pen, and fish were put in the other pens. This practice, while better than carrying no ice at all, was not effective, and it was not until fishermen began to mix the ice with the fish that icing aboard vessels made possible the landing of high-quality fish. The regular use of ice during overland shipments began from Boston to New York in 1858.

A major value of ice for preserving fresh seafoods is that it has a high latent heat of fusion[2] so that it is capable of removing large amounts of heat as it melts without changing its temperature at 32 °F (0 °C). Of course, once it melts, the heat of fusion will have been absorbed, and its temper-

[1]In this context, fresh signifies never having been frozen.

[2]The latent heat of fusion is the amount of heat required to change a given weight of a solid to a liquid without changing its temperature. In the English system, the weight used is one pound (Btu). In the metric system, the weight used is one gram (calorie).

Icing fish.



ature will begin to increase as it is exposed to more heat.

During the transition from ice to water, 1 pound (454 g) of ice absorbs 144 Btu (British thermal units). Since 1 Btu (252 calories) is defined as the amount of heat required to raise the temperature of 1 pound (454 g) of water by 1 °F (0.56 °C), then the removal of 144 Btu (36.3 Kcal) from a 6 pound (2.7 kg) fish, which contains about 75 percent water, will lower the temperature of that fish 32 °F (17.8 °C) from an ambient temperature of 64 °F (17.8 °C) to 32 °F (0 °C). The calculation involved is 144 ÷ (6 x 0.75).

This would suggest that fishermen should take about one-sixth as much ice as the weight of fish they expect to catch when the ambient temperature is about 64 °F (17.8 °C). However, we have to take into account the fact that the ice continually cools the pen walls as well as the air around it from the moment the ice is loaded on the vessel, and it is expected to keep removing heat from the system as well as the heat generated by the fish, once the fish are added, until such time as the fish are landed. The amount of extra ice needed for accommodating the heat which the system receives from the environment will vary depending on time of year, amount of insulation, length of trip, etc. This is bound to be quite high. At any rate, fishermen should take enough ice to maintain the fish temperature at about 32 °F (0 °C) at all times. The amount of ice taken on a trip will be best worked out for each vessel, but it would probably be from one-fourth to one-half the weight of the expected catch.

Since the spoilage of fish starts just after they die, and since the spoilage rate is largely dependent on the temperature, the sooner the fish can be cooled the better. This is precisely the reason that the quality of fish is preserved longer when there is an adequate amount of ice, and it is well dispersed among the fish. When the ice is in small particles, such as flakes, it does a more effective job of cooling than when it is in large pieces. This is because smaller ice particles give greater contact between fish and ice, and the rate of heat removal depends on the size of the contact area. Another advantage of small ice particles is that it avoids damaging fish in the lower part of the pens. Large pieces of ice can exert point forces (from the pressure developed in the lower part of the pens when they are filled) and thereby damage fish.

Although this paper does not cover the modification of ice with bacteriostats, it is important to point out that the ice must be sanitary. Obviously, both ice and water that come in contact with food must be of potable quality. The need to ensure the quality of the ice is not emphasized merely to meet legal compliance which is conerned with public health but rather to minimize the sources of bacteria and other agents of spoilage.

Use of Chilled Seawater

Chilled seawater (CSW) is discussed here because, in essence, it is an extension of the use of ice. That is, it is the end point to which can be carried the principle of maximizing surface contact (the smaller the ice particles, the greater the cooling rate, and molecules of cold water can be considered to behave as minute articles of ice).

In CSW, the fish are surrounded with a mixture of ice and water, thereby achieving maximum contact between fish and coolant. When enough ice is added to the system, it will bring the temperature of the water down to 32 °F (0°C), and it will continue to remove the heat from the water, that the water, in turn, removes from the fish. The transfer of heat from the fish to the water and from water to ice will continue until the system is brought to a state of temperature equilibrium. Actually, a uniform temperature may never really be attained, because the system is dynamic, continually absorbing heat from the environment and from the bacteria in the fish. However, provided there is sufficient ice in the system, a point will be reached where the average temperature of the system cannot be reduced further.

CSW is effective because the water component of the CSW establishes maximum contact between the cooling medium and the fish. Therefore, the cooling rate of fish in CSW is higher than that of fish in ice.

CSW has sufficient advantages over ice alone to warrant its adoption by commercial fishermen for cooling their catch (Hulme and Baker, 1977). These authors reported that CSW cooling is fast, bringing the fish temperature down to 32 °F (0°C) within 4 hours and maintaining the temperature quite uniformly. Temperature uniformity is enhanced by the thorough mixing due to the action of the sea, as one might expect. There is no need to declump ice at sea; however, seawater must be added to the ice as soon as possible. Otherwise, the ice tends to clump before a slush can be obtained. The fish are less damaged in CSW because of the bouyant effect of the water. Also, fish can be unloaded very quickly with pumps.

In our own work (Baker and Hulme, 1977), we observed that whiting, herring, and other fish may be scaled by the agitation to which they are subjected. This may be an advantage if the fish are to be scaled anyway, as they would be in most processing operations. On the other hand, if the fish were destined for a market that required the scales to remain on the fish, then CSW holding would not be suitable.

There have been reports of the development of discoloration of fish, of rancidity, and of salt absorption during their holding in refrigerated seawater which would have to hold true for CSW (Roach and Tomlinson, 1969; Peters, Carlson, and Baker, 1965). We did not encounter these problems, however. The one concern with CSW is that the holds must be of special construction to prevent the buildup of large surge forces in heavy seas. This may be prevented by the installation of perforated baffles (Baker and Hulme, 1977).

The ice requirements used in our studies were governed by an established ratio of one part ice, two parts

seawater, and seven parts fish. Therefore, for every ton (0.9 t) of fish we expected to catch, we put into the hold 286 pounds (131 kg) of ice. At the first opportunity, 571 pounds (259 kg) (about 68 gallons or 257 liters) of seawater were added. Accordingly, if one had an insulated hold or compartment with a capacity of 10 tons (9 t), he would start out by putting 1 ton (0.9 t) of ice in the hold. He would add 2 tons (1.8 t) of seawater as soon as possible (not harbor water, because it is not clean enough). Two tons (1.8 t) of seawater are equal to about 480 gallons (1,817 liters). Then the hold would be filled to capacity with fish, resulting in a mixture of 1:2:7 (ice:seawater:fish). It should be noted that the reason why a relatively small amount of ice was adequate in our CSW work is because the holds of the vessel that we used were well insulated. Both insulation and ambient temperatures have major influences on ice requirements.

Refrigerated Seawater

In ordinary application of refrigerated seawater (RSW), the seawater is usually cooled by mechanical refrigeration. Thus, RSW, as opposed to CSW, is not as limited in its role of removing heat, and there is a reasonable control of temperature over a range that is not possible with CSW. In addition, it has all the advantages described for CSW and, unlike ice and CSW, it can be used for superchilling fish (see next section).

RSW systems may vary, but the basic components are a pump to bring seawater into the vessel and to circulate the RSW, a heat exchanger to remove heat from the seawater, a mechanical refrigerator to discharge heat from the system, a circulatory system for transporting the refrigerant between the heat exchanger and the refrigerator, and a sparging system for spraying the RSW over the catch or a tank to contain the fish and RSW. Auxiliary equipment can, and in some cases may have to be added; i.e., a filtering system, a holding tank for the chilled RSW, a system for controlling the sanitary quality of the water, and a system for removing fish oil.

The designs of a RSW system and its individual components are important (Peters, Slavin, Carlson, and Baker, 1965). Critical among these is the design of the heat exchanger. If it is not properly designed, the RSW may freeze and cause the system to fail. Even when the heat exchanger is of appropriate design, the RSW could conceivably freeze if its rate of flow is too slow. The pump(s) has to be corrosion resistant and have a relatively high capacity. The entire system must be designed, especially the circulatory system (pipes, fittings, valves, etc.), so as to prevent the growth of microbial colonies which can be the source of contamination that can easily be carried to the fish by the RSW. The system must be easily cleaned, especially the tanks that are used to hold the fish.

The earliest commercial use of RSW occurred in the early and middle 1920's to cool menhaden. It has been used to preserve the quality of sardines. In some cases, the brine has been made by the addition of salt to fresh water, especially when there was reason to believe that the available seawater was not satisfactory because of contamination or other deterrent. In the 1950's, Canadians used RSW for preserving the quality of salmon and halibut both on the vessel at sea and in trucks on shore (Roach et al., 1961). While RSW has many advantages, its use has by no means proliferated. It has advantages that result in stabilizing the quality of fish for periods of about 1 week. However, while RSW controls temperature exceedingly well, contact with the fish for periods longer than 1 week may have deleterious effects that result in undesirable changes in odor and flavor (e.g., rancidity) and in appearance (e.g., loss of pigment from skin).

Although RSW should have significant long term preservative effects, empirical data do not support the theory. Carbon dioxide (CO_2) has been added to RSW in recent experiments as an adjunct preservative. The CO_2 lowers the pH which has a beneficial effect on the quality of the fish; but because it does lower the pH, it then enhances the corrosiveness of RSW components to intolerable levels. The latter problem has been circumvented by using components that are coated with corrosion resistant materials. When this is done the RSW system containing CO_2 has shown an effective inhibition of bacterial growth and an increase of at least 1 week in the shelf life of the fish (Barnett et al., 1971).

Superchilling

Superchilling, as used for preserving seafoods, has been defined as the lowering of the temperature of the flesh to within the range from -3° to -1°C (26.6-30.2°F) (Carlson, 1969). The process also has been labeled "supercooling," "light freezing," "partial freezing," and "very poor freezing."

Pure water freezes at 0°C (32°F), but its freezing point is depressed when it contains dissolved substances. The water in biological systems (plants and animals) contains varying amounts of dissolved substances; therefore, the freezing of seafoods occurs below the freezing point of pure water. When the temperature of seafoods is lowered, the physical change to a hardened mass occurs gradually at rates that are fastest in the beginning and slower as the temperature drops. The water in the seafood is not spontaneously frozen at any given temperature. As the flesh temperature is lowered, the first water molecules are frozen at slightly below 0°C (32°F). Successively more is frozen as the temperature continues to fall. According to Power et al. (1969), as the temperature of fish muscle is lowered to -1°, -2°, -3°, and -4°C, (30.2°, 28.1°, 26.6°, and 24.4°F), the percent of water frozen is 19, 55, 70, and 76, respectively.

At first, the rate of freezing of the water in fish is relatively rapid; and by the time the temperature is lowered to only -6°C (21.2°F), about 80 percent of the water is frozen and the flesh is rigid, even though the remaining 20 percent of the water is not frozen. At

Superchilled haddock fillet.

this point, the rate of freezing is sharply reduced, and a further decrease of about 36 °F (20 °C) (down to -14.8 °F or -26 °C) will freeze only about an additional 8 percent of the water (leaving about 12 percent of the water in the system still in the liquid state). It is not until the temperature is lowered to about -67 °F (-55 °C) that all of the water will appear to be frozen. (While the foregoing data may vary slightly, it accurately represents the processes.) A typical example of this process is described in Charm (1971).

From this, we can see that superchilling will involve the conversion of at least some water to ice, the amount depending on the equilibrium temperature to which the system is finally brought. Provided that the temperature is not permitted to go below 26.6 °F (-3 °C), superchilled seafoods will not become rigidly frozen. Thus, superchilling is accurately defined as partial freezing.

The first record of superchilling was reported in about 1935 (Carlson, 1969), and it involved the use of brine (at about 26.6 °F (-3 °C)) as the refrigerant, resulting in extended shelf lives for whole fish. In the first major use of superchilling, mechanical refrigeration was used to hold fish aboard fishing vessels at about 30 °F (-1.1 °C) (Ranken, 1963).

Reports on the preserving effectiveness of superchilling fish leave little doubt as to the considerable increase in the shelf life of the product. However, according to Carlson (1969), certain disadvantages surfaced in subsequent evaluations of the process by research teams from England and later by teams from Canada, The Federal Republic of Germany, and the United States. Degradation of appearance and texture and excessive drip loss were also found and confirmed (Power and Morton, 1965). Some of the quality degradation was attributed to the partial freezing that actually occurs during superchilling. The recommendations that derive from these subsequent evaluations are that superchilling is effective and practical, provided that the temperature does not fall below the point where freezing is discernible (about 28.4 °F or -2 °C) and that the time of holding does not exceed 12 days. The use of seawater with no added salt will insure that the temperature of the fish will not be lowered too much because seawater freezes at about 28.4 °F (-2 °C).

Freezing

The preserving of foods by freezing goes back into antiquity, having been used by such ethnic groups as Eskimos and Indians in certain cold areas. Fish caught in the winter months in cold climates were frozen and held frozen in the cold ambient air. Red meats were also frozen and held in natural, freezing, ambient conditions.

The industrial freezing of foods was introduced by Clarence Birdseye during the 1920's when he developed a process for freezing foods in small packages suitable for retailing. He found that the quality of a variety of foods, including fish, fruits, and vegetables could be preserved for months by freezing and low temperature storage. Subsequent development in freezing equipment and techniques has gradually evolved into the highly sophisticated frozen food and marketing distribution system available to us today. Important events in the development of the frozen food industry and a summary of its past and present are described by Fennema (1976). Much of the refrigeration equipment and techniques used in the frozen food industry has been connected with the preservation of fishery products.

While fresh seafoods are more acceptable to U.S. consumers and carry a higher retail value than frozen seafoods, this is an anomalous situation because the production costs of frozen seafoods are higher than for fresh seafoods. High quality seafoods are worth their extra production costs because they have a much longer shelf life than fresh seafoods, and after purchase they may be put into domestic frozen storage directly without the need to package them and to expend the energy required to freeze them.

Regardless of the comparative acceptabilities and values of fresh and frozen seafoods, much of the seafoods consumed in this country are frozen at one time or another before they reach the point where they are consumed. This is because of the long times involved in the distribution and especially holding of seafoods.

While the use of ice, CSW, or superchilling is adequate for preserving the quality of seafoods for short periods, none of these processes operates at low enough temperatures required to protect quality for long periods. Seafoods may retain their quality for many months if they are properly packaged and held at suitably low temperatures (below 0 °F or -17.8 °C). Numerous data demonstrate that many seafoods remain virtually unchanged in their quality for periods longer than 1 year when they are held at -40° (-40°F = -40°C). Even at -20 °F (-28.9 °C), long shelf

lives have been reported for seafoods.

The need to thaw frozen seafoods prior to reprocessing in food plants or for domestic use is one undesirable aspect of freezing. Thawing is time consuming and, in some cases, is associated with loss of product quality. It normally takes longer to thaw food than to freeze it under similar heat transfer conditions. In other words, it takes longer for the temperature of a food to go from -10°F (-23.5°C) to 60°F (15.7°C) than it takes the temperature of the food to go from 60°F to -10°F. This is because the thermal conductivity of ice is about four times greater than that of water (Baumeister and Marks, 1966).

This difference in thermal properties affects the surface of the food which is frozen during most of the freezing cycle and unfrozen during most of the thaw cycle. Thus, during freezing, immobilization of surface microorganisms occurs early in the process before much deterioration can occur; conversely, in the thawing process the surface is thawed first and surface microorganisms are provided with good growing conditions for nearly the entire thawing period.

Foods packaged in small units defrost in a few hours at room temperature and during this time are not subject to an undesirable amount of decomposition due to bacterial growth. However, seafoods frozen in bulk (i.e., large fish blocks) may present a defrosting problem. Because bulk-frozen foods take a long time to defrost and because the rate at which the food defrosts depends on the temperature to which it is exposed, there may be a tendency to defrost the food at relatively warm temperatures. When this is done, the surface of the food is subject to microbial spoilage before the inner portions defrost.

Some methods have been developed to alleviate this problem. Refrigerator defrosting (holding at temperatures of 35-40°F or 1.7-4.5°C) is probably the best method of defrosting bulk-frozen foods when no fast method is available. This would apply to large whole fish since bacterial or mold growth would be limited under these conditions. However, in industrial processing, where bulk-frozen products are thawed as an intermediate step in the manufacture of the company's line of products, the refrigeration space required may be so large as to discourage this practice.

Frozen halibut in cold storage.

With microwave energy, food can be thawed rapidly and with virtually no quality loss. That is because microwaves, by their unique character, cause a temperature rise throughout the product almost simultaneously. The microwave beam penetrates foods with an alternating current. In alternating current, the charge alternates between positive and negative. Because water molecules are polar (i.e., they have positive and negative ends), they are put into a twisting motion due to the alternating current which attracts first the positive end of each molecule then the negative end at a rate of millions of times per second. The twisting action of the water molecules creates considerable friction which generates heat. Ice is not affected by microwaves, but neighboring unfrozen wa-

ter molecules (frozen foods contain some unfrozen water) generate the initial heat that melts adjacent ice to release more water which accelerates the heating.

Since the heat generated in foods by microwaves is quite rapid (about 10 times more rapid than by baking), when uneven heating in a frozen product does occur, the temperature differences within a food can become great. This, however, happens only under certain conditions, and it can be dealt with quite easily. For this condition, and also when one wants to ensure uniform temperature control, one solution is to apply the microwave energy in intermittent bursts. By this technique, the absorbed thermal energy generated during a burst of microwaves is allowed to be distributed by conduction during the intervals between the bursts, thereby permitting the temperature of the food to increase more uniformly albeit more slowly. Modern developments, such as wave guides, have improved the distribution of microwave energy.

The particular advantage of using microwave energy for thawing foods is that deterioration by microorganisms is not a factor. The feasibility and benefits of microwave thawing of frozen meats and fish have been adequately demonstrated, especially for thawing frozen shrimp blocks (Bezanson et al., 1973). Industrial microwave ovens are now used by both the meat and seafood industries.

One potential solution to the problems associated with thawing and the cell damage caused by ice crystals investigated by Charm et al. (1977) is worthy of mention and recommended for further investigation. Basically, the method involves the lowering of the temperature to below freezing (26.6 °F or -3 °C) without forming any ice by imposing a pressure of 272 atmospheres on the product. Lower temperatures are possible.

One aspect of seafood preservation that has variable importance is packaging. Packaging of seafood performs several basic functions (e.g., protection from contamination). In addition, the package has to serve additional functions, the critical one being gas impermeability (Nickerson and Ronsivalli, 1979). Preventing the frozen seafood from having direct contact with oxygen is highly important.

The rate at which foods are frozen is just as important as the temperature at which frozen foods are held and the range of fluctuation of the storage temperature. When foods are allowed to freeze slowly, water molecules, even though they are slow moving, have time to migrate to seed-crystals resulting in the formation of large ice crystals. When foods are made to freeze rapidly, the sluggish water molecules do not have enough time to migrate to ice crystals but instead are "frozen in their tracks," so to speak, forming relatively small ice crystals made up of local water molecules. Rapid freezing may be effected by a variety of methods which include the use of liquid and gaseous refrigerants, cold-air blast, and cold-plate contact.

Liquid Refrigerants

Freezing is most rapid when the food is brought into direct contact with refrigerants (i.e., where the foods are immersed directly in a liquid refrigerant, sprayed with liquid refrigerants, or exposed to cold gases emanating from liquid refrigerants). This is because the removal of heat is proportional to the temperature differential at the food surface, and the direct contact between food and refrigerant tends to maintain the temperature differential at the highest possible value for the particular system.

Brine

Brine may be defined as a salt solution. Both the salt and its concentration may vary, depending on the intended application. The salt is generally sodium chloride, and the solvent is water. The principle that dissolved substances depress the freezing point of water makes brine an effective medium for freezing foods. Thus, salt solutions have lower freezing points than pure water, and brine can be made cold enough to freeze foods which are immersed in it while the brine itself remains fluid. The freezing point of brine is determined by the concentration of the salt.

At salt concentrations up to 23.3 percent, the higher the salt concentration, the lower the freezing point. When the concentration of the salt reaches a value of 23.3 percent by weight, the limit of the trend is reached at a temperature of -6 °F (-21.2 °C). This is the eutectic point for NaCl, and it is the lowest temperature that a NaCl solution will remain fluid. Any further increase in NaCl concentration tends to raise the freezing temperture of the brine.

When one wishes to avoid the use of sodium or when one wishes to depress the freezing point of the brine beyond the limit that can be reached with NaCl, then $CaCl_2$ may be used. It can be seen from Table 1 that, while there is little difference in freezing point depressions between the two salts up to concentrations of about 20 percent, at 25 percent concentration calcium chloride lowers the freezing point of water to a level that cannot be accomplished with sodium chloride at any concentration. Table 1 also shows that calcium chloride can depress the freezing point of water to as low as -67.0 °F (-55.0°C), the eutectic point for calcium chloride. It can be seen that the difference between the

Table 1.—Effect of NaCl and $CaCl_2$ concentrations on the freezing point of water.

Percent salt	Freezing point of aqueous solution of NaCl		Freezing point of aqueous solution of $CaCl_2$	
	°F	°C	°F	°C
0	32.0	0	32.0	0
5	26.7	-2.9	27.7	-2.4
10	20.2	-6.8	22.3	-5.4
15.	12.3	-10.9	13.5	-10.3
20.	2.3	-16.5	-0.4	-17.8
23.300[1]	-6.0	-21.2	—	—
25.	16.1	-8.8	-21.0	-35.3
25.200	32.0	0	—	—
26.285[2]	32.2	0.1	—	—
26.308[3]	38.0	3.3	—	—
29.870[4]			-67.0	-55.0

[1] Eutectic point for NaCl.
[2] Transition point for NaCl.
[3] Saturation point for NaCl.
[4] Eutectic point for $CaCl_2$.

eutectic points for NaCl and $CaCl_2$ is considerable. While the data of $CaCl_2$ are not carried out, it should be noted that further increases in $CaCl_2$ tend to raise the temperature. Despite the versatility of calcium chloride, brine for cooling seafoods is produced from sodium chloride. Calcium chloride is used only when very low temperatures are needed to effect rapid cooling or when cooling bulky products.

From the middle 1910's to the middle 1920's, immersion of fish in brine was the only known method of quick freezing. While new methods for freezing have been developed since then, brine immersion freezing is still an effective and useful process because of its rapidity and because the fish do not lose water. However, the fish can absorb some salt which has a catalytic effect in oxidative deterioration of the quality of the fish during subsequent storage. Nevertheless, brine freezing is still employed in a variety of situations, including some U.S. vessels; however, in U.S. land-based operation, it has been replaced by other freezing methods. Many plants use brine to prechill fish.

One of the problems with the use of brines is their tendency to corrode equipment when their pH is allowed to fall below 7.0, becoming acidic, and when air enters the system. The pH of brine generally falls in the presence of air due to the carbon dioxide contained in air which dissolves in the brine to form carbonic acid which lowers the pH, and corrosion is enhanced due to the presence of oxygen in the air.

Both corrosion and salt absorption can be reduced without sacrificing the lowering of the freezing point by substituting sugar for some of the salt, provided that the present of sugar is neither restricted nor undesirable. There seems to be no significant conclusions regarding the use of salt/sugar brines except that they accomplish to some degree the objective for which they are used.

Cryogenic Liquids

Cryogenic liquids can be brought to very low temperatures without solidifying. They may be used in direct contact with foods in place of brines. These include liquid nitrogen at -320 °F (-196 °C), liquid carbon dioxide at -108 °F (-78 °C), and Freon-12 (dichlorodiflouromethane) at -21 °F (-29 °C). The number of refrigerants that can be used in direct contact with seafoods is limited because they are required by the Food and Drug Administration (FDA) to meet the same criteria that apply to foods, and only a few of these refrigerants can meet the criteria.

FDA requirements are not the only criteria imposed on the use of liquid refrigerants. Freon-12, although in use by industry for direct contact with foods under FDA sanction over a period of years is now under EPA (Environmental Protection Agency) scrutiny because of its perceived damage to the Earth's atmospheric ozone layer which would lead to reduce protection from the Sun's infrared radiation (Semling, 1979). This consideration is bound to affect future decisions as to choice of refrigerants. The EPA's scrutiny directed at Freon-12 includes other halocarbons even though they may be used in closed systems and do not come in direct contact with foods.

While freezing food by various methods that involve direct contact between them and liquid refrigerants is practiced widely, the holding of frozen foods is largely done in rooms that are kept at freezing temperatures by systems that use any of a variety of fluid refrigerants in what are properly described as mechanical refrigeration systems. These will be described in the following section. However, at this point, we will continue with the discussion of the cryogenic liquids that are used in these systems.

The refrigerants used either in direct contact with food or in mechanical refrigeration systems are classified into three groups. Group 1 refrigerants, which are neither toxic nor flammable, include carbon dioxide, liquid nitrogen, and the fluorocarbons. Group 2 refrigerants are toxic, flammable, or both. Ammonia, which is used in some of the larger industrial installations, is a representative of this group. Group 3 refrigerants are highly flammable and explosive. They include propane, ethane, methane, ethylene, and propylene. This group has limited use and is used only where a flammability or explosion hazard is already present and their use does not add to the hazard. A description of some of the important refrigerants follows. In refrigeration jargon, which is mainly used to avoid contending with the unwieldly names of many of the refrigerants, they are given numbers with an "R," the R meaning refrigerant (Table 2).

R717. Ammonia, R717, is a very economical and efficient refrigerant because of its low boiling point, -28 °F (-33 °C), and high heat of vaporization (589 Btu/pound or 327 calories/gram) at atmospheric pressure. Although toxic and flammable under certain conditions, ammonia is still

Table 2.— Names and properties of important refrigerants used in the food industry.

Refrigerant	Chemical composition	Chemical formula	Boiling point °F	Boiling point °C	Freezing point °F	Freezing point °C	Heat of vaporization at boiling point Btu/lb	Heat of vaporization at boiling point cal/g
R717	Ammonia	NH_3	-28	-33.3	-107.9	-77.7	589.0	327.0
R12	Dichlorodiflouromethane	CCl_2F_2	-21.6	-29.8	-252	-157.8	71.04	39.47
R22	Monochlorodiflouromethane	$CHClF_2$	-41.4	-40.8	-256	-160	100.45	55.81
R502	Mixture of 48.8 percent R22 and 51.2 percent R115	$CHClF_2/C_2ClF_5$	-49.8	-45.4	—	—	76.46	42.48
R115	Monochloropentaflouroethane	C_2ClF_5	-38.4	-39.1	-159	-106.1	54.20	30.11
R728	Nitrogen	N_2	-320.4	-195.8	-415.5	-248.6	86.0	47.8
R744	Carbon Dioxide	CO_2	-109.2	-78.4	-69.9	-55.6	247.0	137.1

one of the best and most widely used refrigerants. It is used extensively in large commercial and industrial refrigeration plants. In small and medium-sized commercial plants, ammonia, which is a strong irritant of eyes, throat, nose, and lungs, is being replaced by Freon 12, 22, and 502, which are Group 1 refrigerants and have many advantageous physical properties, as well as being much safer.

R12. Dichlorodiflouromethane, or R12, has a boiling point of -21 °F (-29.4 °C) at atmospheric pressure and a latent heat of vaporization of 71 Btu/pound (39.5 calories/gram). Presently, it is the most widely known and widely used refrigerant. It is used in many small commercial refrigeration plants and has a multitude of applications, ranging from small household refrigerators and air conditioners to large centrifugal units for normal- and low-temperature plants and has been used to obtain temperatures as low as -130 °F (-90 °C) although other refrigerants are better suited to maintain temperatures in that range.

The disadvantage of R12 is that unlike ammonia, it is not compatible with moisture and care must be exercised to remove all air and moisture which otherwise would cause excessively high head pressure and freezing of expansion valves.

R22. Monochlorodifluoromethane, or R22, has a boiling point of -41 °F (-40.6 °C) at atmospheric pressure and a latent heat of vaporization of 100.5 Btu/pound (55.8 calories/gram). Its physical properties are similar to those of R12 except that it has a lower boiling point, and it operates at a higher discharge pressure than R12. It is used in place of R12 for low temperature applications.

R502. R502 is a mixture of monochlorodifluoromethane (48.8 percent) and monochloropentafluoroethane (51.2 percent) (R22 and R115, respectively). It is especially well suited to low temperature applications providing considerable capacity gain over R22 but with discharge temperatures comparable to R12. It has a boiling point of -50 °F (-46 °C) and a latent heat of vaporization of 76.5 Btu/pound (42.5 calories/gram). R502 is a recent addition to the refrigerant list but is rapidly becoming recognized and is replacing R22 in many applications.

R728. R728, liquid nitrogen, has a boiling point of -320 °F (-196 °C). The latent heat of vaporization of liquid nitrogen is 86 Btu/pound (47.8 calories/gram). However, the cold vapor is capable of absorbing another 80 Btu/pound (44.4 calories/gram) in warming up to -40°. Consequently, there is a usable heat-removal capacity of about 166 Btu/pound (92.2 calories/gram).

R744. R744 is the refrigerant designation for carbon dioxide, also known popularly as dry ice. R744 has a boiling point of -109.2 °F (-78.4 °C) and a heat of vaporization of 247 Btu/pound (137 calories/gram). In warming up to -40°, it will absorb another 14 Btu/pound (7.8 calories/gram) for a usable heat-removal capacity of about 260 Btu/pound (144.3 calories/gram) which is 57 percent greater than liquid nitrogen. The advantage of liquid nitrogen over carbon dioxide is that it has a much colder starting temperature.

Both R728 and R744 are suitable for cryogenic freezing, and the choice is mainly an economic one, depending on availability and cost at the location.

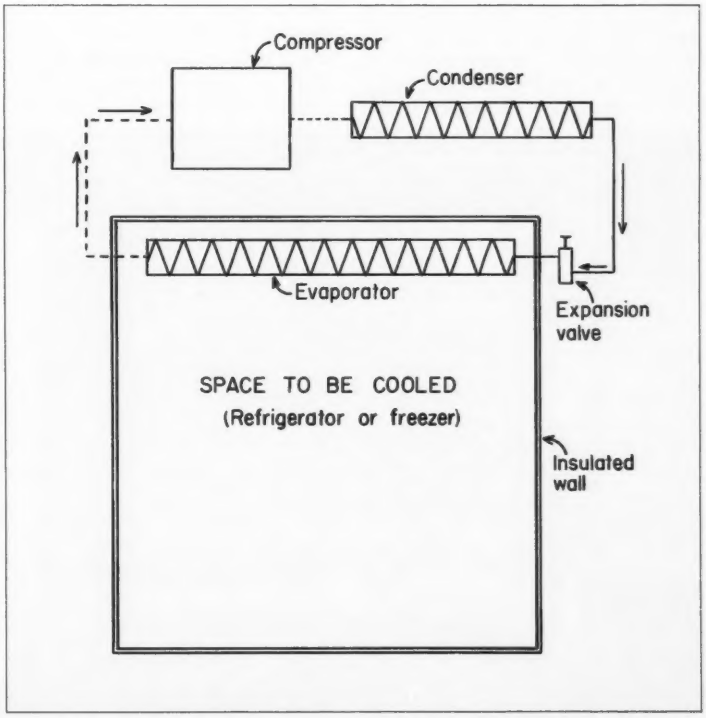


Figure 1.—Basic elements of mechanical refrigeration.

Mechanical Systems Using Liquid Refrigerants

A mechanical refrigeration system consists of an insulated area or room (the refrigerator) and a continuous, closed system consisting of a refrigerant, expansion pipes or radiator-type evaporator located in the refrigerator, a pump or compressor, and a condenser (Fig. 1). The compressor and condenser are located outside the refrigerator. The refrigerant, such as ammonia or one of the freons, flows into the expansion pipes as a liquid. Here it evaporates to a vapor and in changing from the liquid to the vapor phase it absorbs heat through the evaporator. The vapor is pulled into the compressor by the suction action of the pump and is then compressed into a smaller volume of hot gas. The latter action causes the gas to heat up and this heat must be taken out. This is done by passing the compressed gas through a system of pipes or radiators usually cooled by water, or sometimes by forced air. Cooling the compressed gas liquefies it, whereupon it is then returned to the evaporator in the refrigerator. The conversion of the gas to a liquid also produces heat which is transferred to the water or air of the condenser. Special valves at both ends of the evaporator allow the required flow of liquid refrigerant in and of vapor out of the expansion system in the refrigerator.

There are a number of ways in which refrigeration may be applied to the insulated area which is to be cooled. Expansion pipes where the refrigerant is evaporated may be located along the walls of the freezer. In this case natural circulation of air (the cold air being heavier) may be depended upon to refrigerate areas within the room away from the expansion pipes, or some type of forced air circulation may be used. In some instances radiation-type evaporation units are used. A fan which blows air through the radiator fins provides circulation of cold air throughout the freezer.

A variety of methods are associated with the use of liquid refrigerants. The following discussion is limited to only some of the systems that are in current use.

Plate Freezing. In plate freezing (Fig. 2), layers of the packaged product are sandwiched between metal plates. The refrigerant (a fluorocarbon such as R12) is allowed to expand within the plates to provide temperatures of -28 °F (-33.3 °C) or below, and the plates are brought closer together mechanically so that full contact is made with the packaged product. In this manner the temperature of all parts of the product is brought to 0 °F (-17.8 °C) or below within a period of 1.5-4 hours (depending upon the thickness of the product). The packages are then removed, put into cases, and stored.

Continuous operating plate freezers are now in use. In one such system the freezer is loaded at the front and unloaded at the rear after completion of the freezing cycle. This is done automatically and continually. In another continuous system, the packages are fed automatically on belts which place them in front of eight levels of refrigerated plates. The packages are slid into the spaces between the plates and the plates closed to provide contact. As freezing proceeds, the packages are advanced by a system such that with each opening of the plates the packages are advanced by one row with a new set of packages entering the front row. By the time the packages reach the far side of the plates, they are completely frozen, and they are pushed out of the freezer and unloaded to be cased and stored.

The vertical plate freezer was developed mainly for freezing fish at sea. It is usually used in sodium chloride brine freezing wells and consists of a number of vertical plates forming partitions in a container with an open top. The product is simply dropped into the brine from the top. This type

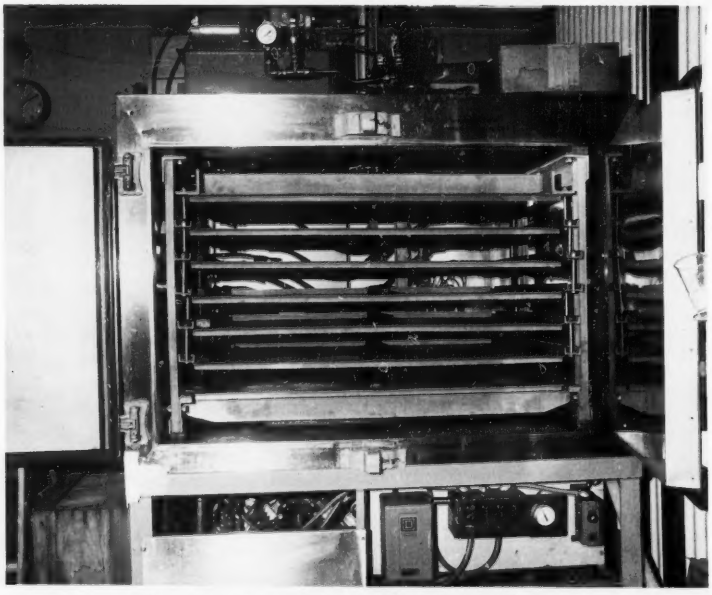


Figure 2.—Closeup view of plate freezer chamber.

of freezer is widely use by the tuna industry. (Calcium chloride can be used when faster cooling times are desired.)

Immersion Freezing. Products either packaged or unpackaged can be frozen by direct immersion in cryogenic liquids. The products may be carried through the refrigerant by a submerged conveyer. When the product to be frozen is large (e.g., whole large tuna and swordfish), it may simply be immersed in a tank of refrigerant. There are not many choices for freezing large fish because of the relatively long freezing times required. Here, direct immersion effects rapid freezing.

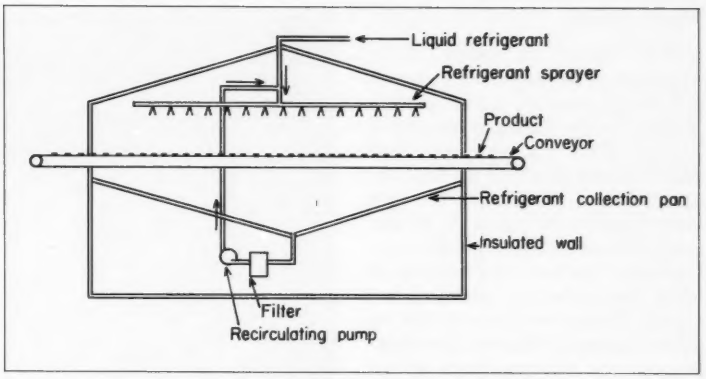


Figure 3.—Continuous liquid-refrigerant freezer.

Spray Freezing. The freezing of foods by direct sprays of cryogenic liquids (nitrogen and carbon dioxide) is widely used. In this process individual food portions are placed on a moving stainless steel mesh belt in an insulated tunnel where they are sprayed with liquid refrigerant (Fig. 3). Excess refrigerant is recovered, filtered, and recycled. The food leaves the freezer in the frozen state and is thereafter packaged, cased, and stored. This method provides very fast freezing and is being used especially for some marine products such as the various forms of frozen shrimp. When the liquid refrigerant is evaporated, the still cold vapors are used to precool and temper the product entering the freezer. The very high freezing rates associated with liquid nitrogen freezing results in improved texture, particularly in the case of certain fruits and vegetables.

In the case of carbon dioxide (CO_2) freezing, in order to utilize the liquid CO_2, it must first undergo a change of state to freeze the product at or near atmospheric pressure. Since liquid CO_2 cannot exist at pressures of less than 69.9 psia[3] (4.9 kg/cm²) when it expands from its storage pressure to atmospheric pressure, both gaseous CO_2 and solid dry ice are formed; and depending on the design of the equipment, either the production of CO_2 gas or CO_2 snow can be maximized. The CO_2 snow at -108 °F (-78 °C) then comes in contact with the product and, combined with the gases, effects the freezing process.

The liquid freon (LF) system is the newest system on the market and uses specially purified dichlorodifluoromethane (R12). The product is carried into the unit by a conveyer and dropped into a moving stream of R12 on a pan to separate and crust-freeze food particles as they are distributed and moved from the drop zone of the freeze belt. The freeze belt carries the food under sprays of refrigerant to complete the freezing process. A third conveyer then carries the food out of the freezer. R12, which has been vaporized as a result of heat extraction from the food, is recovered and reliquefied by contact with a condenser located above the freeze conveyer. Condensed refrigerant is collected in a sump and recycled to the spray nozzles. The system is very efficient because only minimal amounts of refrigerant are lost, about 0.5-0.7 kg per 45.5 kg (1-1.5 pounds per 100 pounds) of processed food. Most of the losses are residual amounts left on the food, and these evaporate very rapidly.

Refrigerated Air

Although air is fundamentally a poor conductor of heat, the fact that its density changes as its temperature changes permits its use as a contact refrigerant, albeit relatively slowly. Cold storage warehouses can lower the temperature of a food that is at higher temperature than the air within the cold room by conduction at the interface between the food (or its package or overwrap) and the air within the room which is put into motion as its specific gravity changes. That is, air made cold by the evaporator (or expansion pipes) is made more dense and tends to migrate to the floor of the cold room forcing the warmer air to migrate upward. Thus, the food surfaces are continually exposed to cooler, moving air molecules that acquire heat from the food by conduction, then are lifted by the buoyant force of the denser air molecules away from the food whereupon other cold molecules repeat the cycle. When foods are not protected by packaging or an ice glaze that is impermeable to water vapor, or otherwise prevents loss of moisture, the cold air which is also relatively dry will condense water molecules and tend to dehydrate the food as well as cool it. The water carried by the air is then condensed on the evaporator coils where is can be seen as "frost."

[3]Pounds per square inch absolute. This means that when the pressure is measured with a pressure gauge, the value of the prevailing barometric pressure must be added to the gauge pressure to obtain psia.

Sharp Freezers

Sharp freezers employing the refrigerated air principle, were used in early installations and are still generally used on the Pacific coast and in Alaska. They are essentially cold storage rooms that cool the foods by air convection. In some of the early sharp freezers, shelves made of pipe grids or metal plates containing the refrigerating medium were installed on which the product to be frozen was placed. There is no rapidly circulating air so freezing is relatively slow depending on the size and shape of the product and the manner in which it was distributed on the shelves.

Jacketed Freezers

The jacketed freezer (Fig. 4) is designed so cold air circulates through an enclosed jacket completely surrounding the product storage space. It is simply a room within a room and allows storage at near 100 percent relative humidity and at a constant temperature. These conditions greatly reduce the weight loss of unpackaged foods and frost formation inside packaged frozen foods. The jacketed principle, although a good one, has not been accepted by the industry nor used to any great degree owing to prohibitive building costs.

Blast Freezers

Blast freezers are generally rooms or tunnels in which cold air is circulated by one or more fans through an evaporator and around the product to be frozen. Air blast freezers are generally preferred when unwrapped products of irregular size are involved (i.e., large fish in the round). The blast freezer may be of the batch type, semicontinuous or continuous, depending on whether the product is supported on racks, trucks, or moving belts (Fig. 5). Some of the latest designs are very efficient and space requirements are minimal due to a vertical spiral configuration of the continuous conveyer which moves the product throught the freezer. These are known as belt freezers but, along with tunnel freezers, are still basically of the air blast variety.

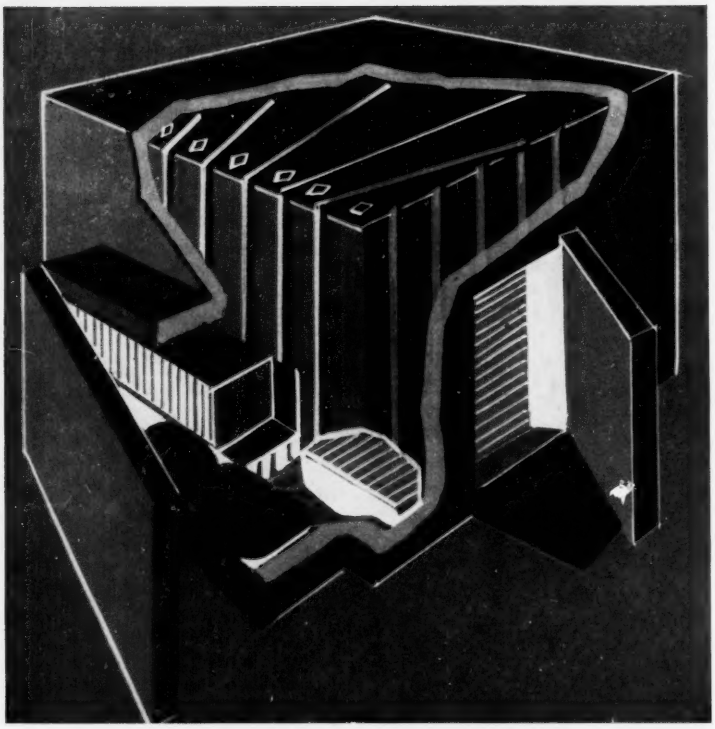


Figure 4.—Jacketed freezer, cross-sectional view.

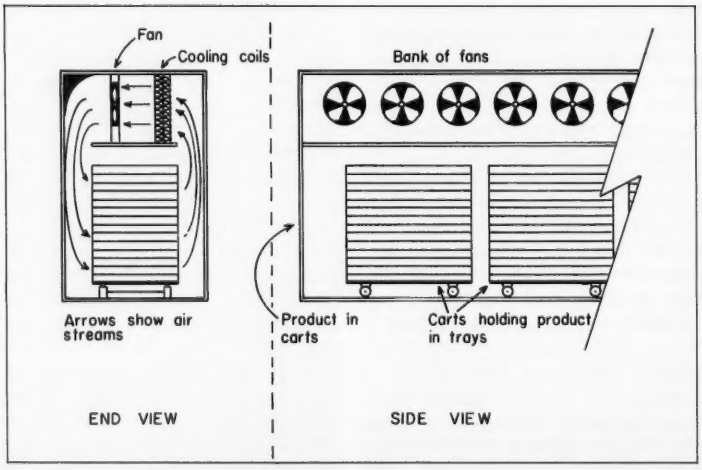


Figure 5.—Tunnel blast freezer.

Fluidized Bed Freezers

When particles of fairly uniform shape and size are subjected to an upward air stream, they are said to become fluidized. By this principle, food products of small uniform size, such as scallops and krill, can be frozen. Depending on the characteristics of the product particles and the air velocity, they will float in the air stream, each one separated from the other, surrounded by air and free to move. Under these conditions, the mass of particles behaves like a fluid. The product can then be frozen and simultaneously conveyed by air without the need of a mechanical conveyer. The advantage over belt freezing is that the product is truly individually quick frozen (I.Q.F.) and even applies to foods that tend to agglomerate.

Dehydrocooling

Dehydrocooling is the lowering of the temperature as a result of removal of water by evaporation. It is a practical method in current use for some applications, especially for cooling leafy vegetables. In practice, the process is a simple one involving the controlled evaporation of moisture from the surfaces of products to be cooled.

Water and substances containing it maintain a water-vapor pressure (that depends on temperature) above them in a state of equilibrium. Although the system is a dynamic one (i.e., water molecules are continually being vaporized while vaporized molecules are continually being condensed), the equilibrium is maintained for any given temperature. This is because the number of molecules being vaporized equals the number being condensed. In this condition, the heat lost by evaporation is regained by condensation.

This equality always exists until there is a change in conditions such as a change in temperature or pressure. A drastic disturbance to the system occurs when a vacuum is created in a chamber containing water or a substance containing water. The vacuum creates a reduction in vapor pressure which in turn creates a sudden drop in the condensation rate while simultaneously accelerating the evaporation rate. During this rate imbalance, the heat lost exceeds the heat gained, and there is a net cooling effect. If the vacuum is maintained, the cooling effect can be substantial, and foods can be cooled to below freezing temperatures relatively quickly.

Although dehydrocooling also can dehydrate the product, this can be nullified by the addition of water to the system through an internal water sparger. Employing a water sparger to prevent dehydration, Carver (1975) found that he could cool headed and gutted whiting from a temperature of about 59°F to 32°F (15°C to 0°C) in about 18 minutes (Fig. 6).

Beckman (1961) was granted a patent for "conserving fresh fish" aboard a vessel. By the Beckman process, the fish are eviscerated, washed, and placed into cylindrical tanks which are connected to a steam jet vacuum pump located in the engine room, which reportedly can reduce the pressure within each tank to about 2 mm of mercury. The tanks resemble vertical retorts and can be loaded and unloaded by baskets filled with fish and which fit into the tank. Each tank is designed to reduce heat gain and contains a water injection system for preventing dehydration of the product. The temperature of the product is brought down to 30.2°F (-1°C) and maintained at that temperature until brought to land. The advantages of low temperature holding and the elimination of oxygen, especially with treatment occurring just after the fish are caught, are obvious.

Use of Jet Aircraft at High Altitude

It is widely known that the temperature at altitudes used by commercial jet-powered aircraft is very low (Fig. 7). The use of jet altitude freezing was proposed as a means of transferring seafoods from the coastal areas of large underdeveloped areas like India to the interior of the country as a solution to transport protein foods from an area of abundance to an area of need where other means of temperature controlled transportation is unavailable.

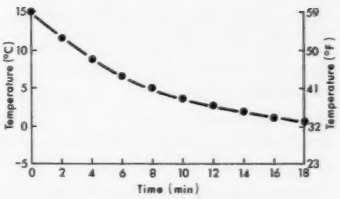


Figure 6.—Dehydrocooling curve for whiting (Carver, 1975).

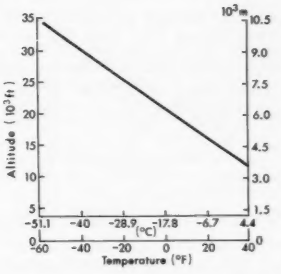


Figure 7.—Ambient temperatures at altitudes above 10,000 feet (3,048 m).

By this proposed method, fresh landed fish are placed in special containers and loaded in specially designed aircraft and flown to inland airfields located more than 2 hours of flying time from coastal areas — sufficient time to freeze the product. The proposal, initiated by an NMFS technologist, was evaluated by the Manager of New Products Investigations, the Boeing Company[4], and given as a problem to the company's engineering staff. Convinced of the potential of the idea, the Boeing group produced a design for a proto-

[4]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

type system using a modified Boeing 727 (Fig. 8) and a special container (Fig. 9). Theoretical problems such as possible aerodynamic interference from the need to pass the outside air through the aircraft and inefficient heat removal by the rarefied atmosphere at jet altitudes were considered, analyzed, and discounted. Although we have not tested this concept, nor do we have any information that anyone else has, theoretically, it has been deemed entirely feasible, and there is no known impediment to its use. With the rising costs for energy to freeze foods, this concept has potential for foods that are destined for long distance transportation; because in these cases, the heat removal is done at little or no cost.

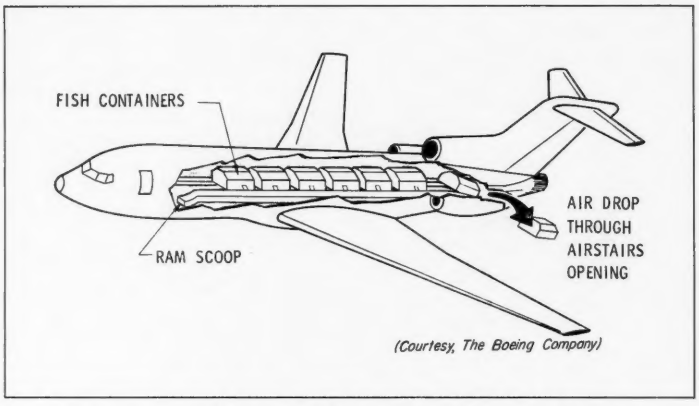


Figure 8.—Modified Boeing 727 for freezing fish at high altitudes.

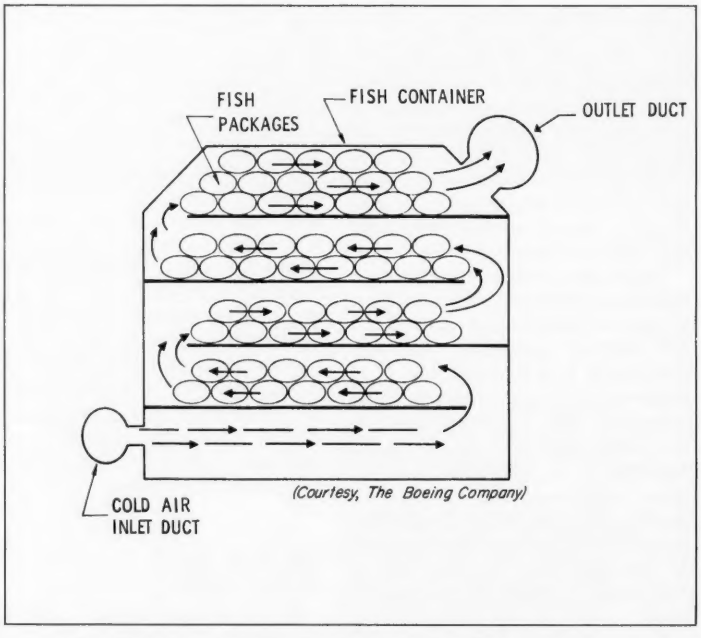


Figure 9.—Container for freezing fish at high altitudes.

Summary

While there are a number of factors that affect the rate at which seafoods spoil, temperature control remains as a major one in the control of their quality. This paper has reviewed the principles, the methods, and the refrigerants used to chill seafoods (32°F or 0°C), superchill them (26.6 to 30.2°F or -3 to -1°C), or freeze them (0°F or -17.8°C or below).

For chilling seafoods, ice, with its high latent heat of fusion, is effective and widely used. When ice is in small particles (i.e., flaked), cooling rates are high and damage to the product is minimized. The amount of ice required varies with each situation, but it should be enough to maintain the product at 32°F (0°C) as long as necessary. In some instances, vessels require about one-fourth the weight of the expected catch or less. In other cases, the requirement could be as high as half the weight of the expected catch. Ambient temperature, length of trip, and degree of insulation are among the major factors that affect the weight of ice required.

Chilled seawater, a mixture of ice and water, chills fish more quickly than ice alone, and by its buoyant effect, prevents damage to the fish. The requirement, again, varies with each situation, but a ratio of 1:2:7 (weight of ice:weight of water:weight of expected catch) has been used successfully with an insulated vessel.

Refrigerated seawater (RSW) usually involves mechanical refrigeration, and, in this case, the product temperature can be lowered below 32°F (0°C) to the superchill range.

This system provides a better and more varied control, but it requires capital equipment and maintenance, and provisions have to be made to inhibit the corrosive effects of the seawater on the RSW components.

Because the seafood spoilage rate is directly related to the temperature, superchilling, which is in the range from 26.6 to 30.2°F (from -3 to -1°C) provides the product with a longer shelf life than chilling (32°F or 0°C).

Freezing occurs over a broad range of temperatures below 26.6°F (-3°C). However, freezing is a stepwise process, and it is not until the temperature is lowered to 0°F (-17.8°C) that enough water is immobilized to effect a reasonable stabilization of product quality for to about 1 year. At higher temperatures, chemical reactions involving enzymes and oxygen will eventually degrade the product quality. At lower temperatures the product quality will remain high for many months and even years.

Because salt lowers the freezing point of water, brine (usually a solution of sodium chloride) is used to freeze large products like whole tuna by direct immersion. Short brine dips are also used to chill fillets. Brines do impart salt to the product, the amount depending on a number of factors, and they do tend to corrode equipment.

Other freezing solutions that can be used for direct immersion of food include liquid nitrogen, liquid carbon dioxide, and a number of halocarbons such as R12 (dichlorodifluoromethane). The halocarbons, including R12, R22 (monochlorodifluoromethane), and R502 a mixture of R22 and R115 (monochloropentafluoroethane), and ammonia are used in mechanical refrigeration systems where there is no direct contact with the food.

Conventional freezing techniques and equipment described include plate freezing which involves sandwiching the product between refrigerated plates; immersion freezing which simply involves the immersion of product in cryogenic liquids; spray freezing which occurs when cryogenic liquids or gases are sprayed directly on the product carried by a conveyor belt; refrigerated air, a slow process occurring when a product is simply placed in a chamber that is held at freezing temperatures (the sharp freezer is an example); the jacketed freezer which involves a double-walled chamber and controls humidity to 100 percent relative humidity is another variation of refrigerated air; blast freezing which involves refrigerated air that is driven across the product by powerful fans; and fluidized freezing which involves the suspension of product particles that are frozen as they are buoyed by cold air forced upwards. A conventional process in the agricultural industry, dehydrocooling, has a demonstrated potential for freezing seafoods. A theoretical, but apparently sound process, jet altitude freezing, has not yet been demonstrated but has a scientific basis for its consideration and has withstood analytical critiques regarding aerodynamic, economic, and technical feasibilities.

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Effect of Arterial Incisions on the Amount of Bleeding and Flesh Quality of Rainbow Trout

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ABSTRACT—Arteries of rainbow trout, Salmo gairdneri, *were severed at the isthmus, nape, and caudal peduncle, and blood loss was measured. The greatest amount of bleeding occurred with the caudal penduncle cut, resulting in a loss of blood weighing 2.29 percent of the total body weight. The effects of delayed bleeding and the use of an anticoagulant, also studied, were of no benefit. The quality of flesh, after being frozen up to 8 months, was superior for bled fish as evaluated by appearance, odor, and lipid stability.*

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Introduction

Slaughter practices used in animal industries are not used in most fisheries. In the animal industry, the animals are maintained quiescent before slaughter, slaughtered, and bled immediately. In fisheries, struggling fish are sometimes stunned by a blow on the head or by electric shock to facilitate handling, but bleeding is rarely done. Most commonly, a landed fish is directly placed in the hold and processed later.

Adequate research has not been done to show the effect of bleeding and stunning on fish flesh quality although the literature indicates advantages from these practices. The removal of blood by making cuts or by evisceration has been noted as a means of accelerating death (Cobb, 1900; Jarvis, 1950) and retarding spoilage (Tower, 1901; Tressler, 1920; Jarvis, 1950; Anon., 1970; Boggess, et al., 1973). Bleeding of fish is required in some Norwegian fisheries to improve fish flesh quality (Fjortoft, 1969).

We initiated studies on the effect of techniques of stunning and bleeding on the quality of fish flesh at the National Marine Fisheries Service (NMFS) Laboratory, Seattle, Wash., in 1970. This paper describes effective and practical methods of bleeding fish. In addition, it presents preliminary information to show the improved quality of flesh of bled fish. Data are presented on the amount of blood bled from cuts made at three locations on cultured rainbow trout, *Salmo gairdneri,* and on the effects of an anticoagulant and delayed bleeding. The quality of flesh of bled and unbled fish was compared on the basis of appearance, odor, and TBA determinations (thiobarbituric acid) indicative of lipid stability.

Materials and Methods

Rainbow trout for the study were obtained from the Washington State Department of Game, Seward Park Hatchery, Seattle, Wash., and the NMFS Northwest and Alaska Fisheries Center, Seattle, Wash. Both stocks were just less than 2 years old at the time of testing; their total weight averaged 284 g (9.1 ounces) and ranged from 169 to 455 g (5.1-14.6 ounces). Fork length averaged 28.5 cm (11.2 inches) and ranged from 23 to 34 cm (9.1-13.4 inches). Trout were maintained at a temperature of about 10°C before use.

Main arteries of groups of unfed fish were severed at three loctions that could be cut efficiently. A cut at the isthmus severs the ventral aorta; at the nape, it severs the dorsal aorta and the spinal cord as well, thereby immobilizing the fish; and at the caudal peduncle, it excises the tail and severs the dorsal aorta. One cut at each location was made on each of 10 fish (5 from each hatchery).

The procedure was to net a fish from its holding tank before its daily feeding, maintain it out of water, blot water from it with paper towels, and at the end of 1 minute to make a cut for bleeding. Subjects were bled into individual plastic bags for 5 minutes. The weight of a bled fish and its blood were determined.

Blood that had been bled was washed off the trout with cold water, water was blotted off, and the fish were then weighted. The weight of the bled fish subtracted from the weight of the blood and fish combined provided the weight of blood lost.

Efficiency of delayed bleeding was examined. Twenty trout handled as in the previously described experiment were cut at the caudal peduncle except that the fish were maintained out of water for 20 minutes at 10°C before the cut was made. Combined total weights of fish and of blood bled of the 20 fish were determined.

An anticoagulant bath (3 percent sodium citrate solution) was used to determine if it facilitated bleeding. The procedure was as before for the caudal peduncle cut (immediately after a fish was removed from water) except that the peduncle was immersed in 100 ml of citrate solution immediately after the tail was excised. Total weight of fish and of blood bled of each of the 10 fish used for this

part of the experiment were determined.

The effect of bleeding on the quality of the fish flesh was evaluated on the basis of its appearance, odor, and TBA determinations (Yu and Sinnhuber, 1957). Samples of fish flesh with skin intact were cut from each side of each fish, wrapped in vapor-barrier film, and stored at -18°C. Samples were thawed after 3 and 8 months and used for quality comparison. A part of each sample was skinned and minced. A part of each minced flesh was used for odor evaluation and the other part was mixed along with a similar weight of flesh from four other fish, similarly treated, for TBA analysis. Odor was rated on a scale of 1 to 5 where a rating of 5 was assigned to a normal fresh odor, and progressively lower ratings were given to samples having an increasingly more objectionable odor with a rating of 1 given to a sample having an extreme abnormal odor.

Amount of Bleeding by Procedure and Resulting Quality

Experiments indicated the relative efficiency of bleeding from cuts made at the three locations, the effect of delayed bleeding, the effect of an anticoagulant bath, and the improvement of fish flesh quality from bleeding.

The mean percentage of blood lost in total body weight from a cut at a given location was similar between the rainbow trout from the two hatcheries; however, this varied considerably with cut location (Table 1). A two-way analysis of variance test ($P = 0.05$) indicated the differences between the two stocks of fish was not significant ($F = 0.022$, 1, 29 d.f.), but differences between the cut locations were significant ($F = 20.128$, 2, 29 d.f.). The most effective cut was the peduncle incision that resulted in an average blood loss of 2.29 percent of the total body weight; the isthmus cut averaged 1.88 percent which was somewhat greater than the nape cut which averaged 1.67 percent. The 2.29 percent loss from the peduncle cut compares with 2.4 percent removed from rainbow trout with a syringe from the dorsal aorta at the peduncle by Smith (1966).

Delaying the caudal peduncle cut by 20 minutes after the fish is removed from water reduces bleeding efficiency. A delayed cut resulted in loss of 1.50 percent of total body weight in blood, whereas this averaged 2.29 percent for this cut made immediately after a fish was removed from the water.

The amount of blood bled was not significantly different between two groups of fish with excised tails where one group was held in an anticoagulant ($F = 1.207$, 1, 18 d.f.; Table 1).

Groups of bled and unbled fish, compared on the basis of appearance, odor, and TBA determinations, indicated that bleeding produced a superior food product. Flesh of bled fish was nearly free of blood, whereas that of the unbled trout was, without exception, discolored a pinkish to red with areas of hemorrhaging in some cases (Fig. 1). Odor tests showed the bled trout to be more acceptable; samples of unbled fish were slightly rancid after 3 months of storage while the bled sample did not show any rancidity until 8 months of storage (Table 2). The odor tests were confirmed by the TBA determinations; values were lower for the bled fish after 3 and 8 months with the TBA value similar between the bled fish after 8 months and the unbled trout after 3 months (Table 2).

Experiments of Boggess et al. (1973) on methods of stunning channel catfish, *Ictalurus punctatus*, confirm some of our findings. They determined that immobilization by CO_2 or bleeding (from peduncle and isthmus cuts) were superior methods because they produced flesh of better appearance and better aroma and flavor after 2 months of frozen storage

Table 1.—Amount of bleeding of rainbow trout from a cut made 1 minute after removal from the water at one of three different locations.

Location of cut	Hatchery of origin	No. of fish	Amount of bleeding (% of total weight)		
			Range	SD	Mean
Isthmus	Seward	5	1.73-2.24	0.21	1.89
	Park	5	1.66-2.10	0.17	1.86
	NMFS	—	—	—	—
		10	1.66-2.24	0.18	1.88
Nape	Seward	5	1.42-1.94	0.26	1.71
	Park	5	1.42-1.96	0.23	1.63
	NMFS	—	—	—	—
		10	1.42-1.96	0.23	1.67
Caudal peduncle	Seward	5	2.00-2.57	0.23	2.25
	Park	5	2.02-2.66	0.23	2.33
	NMFS	—	—	—	—
		10	2.00-2.66	0.22	2.29
Caudal peduncle (Immersed in anti-coagulant)	Seward Park	10	1.33-3.22	0.50	2.10

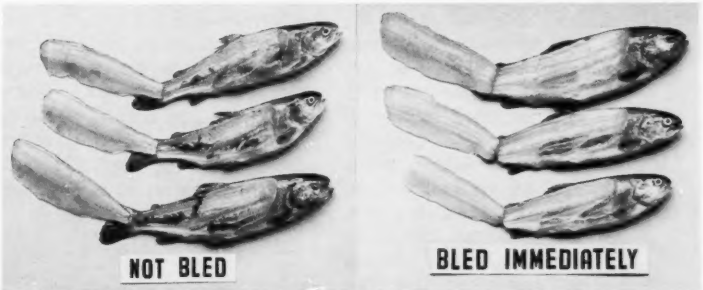

Figure 1.— Appearance of rainbow trout that have been split open to show the remaining blood present in fish that were not bled or bled immediately after they were removed from the water.

Table 2.—Odor and TBA values of raw flesh of samples of bled and unbled rainbow trout stored at -18°C.

Samples	3 months			8 months		
	Odor score[1]	TBA no.	Remarks	Odor score[1]	TBA no.	Remarks
Bled	3.6	1.8	Good quality	2.7	3.1	Slightly rancid
Unbled	2.6	3.2	Slightly rancid	0.6	4.3	Extremely rancid

[1] Rated on a scale of 1-5, where 5 = normal fresh odor; 4 = loss of normal odor; 3 = slight-to-moderate degree of abnormal odor; 2 = moderate-to-strong abnormal odor; 1 = extreme abnormal odor.

than electric or ice immobilization techniques.

Improvement of Product

The cut location affects the efficiency of bleeding with the result that bleeding improves the quality of stored trout flesh.

The two cut locations that should be considered are at the caudal peduncle and at the isthmus of rainbow trout. Greatest bleeding occurs from the caudal peduncle cut; if this results in an unsightly product, then the isthmus cut can be made with some loss in efficiency in bleeding. Based upon our results, the use of an anticoagulant is not recommended for increasing bleeding.

Smith (1966) suggested the blood of rainbow trout in the freshwater environment is 6.2 percent of the total weight of a fish. Assuming similar blood content for our experimental fish, the tail cut removed 37 percent of the blood. Our study shows that the removal of this quantity of blood effectively improves the appearance and reduces the rancidity of rainbow trout flesh that has been stored.

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Movement of Tagged Sea Scallops on Georges Bank

J. A. POSGAY

ABSTRACT — The reported locations of recapture of tagged sea scallops show little evidence of any widespread movement. Eighty-five percent of the reported recoveries were less than 10 miles from the points of release. The direction of movement was generally along the axis of the strongest tidal current.

Introduction

The Atlantic sea scallop, *Placopecten magellanicus* (Gmelin), is the subject of an important fishery for both U.S. and Canadian vessels throughout its range from the Strait of Belle Isle to just north of Cape Hatteras (Posgay, 1957a). Georges Bank, particularly the eastern half, has historically been the most productive fishing ground. During 1957 and 1958, the NMFS Northeast Fisheries Center conducted a tagging program on Georges Bank primarily to investigate growth and mortality rates. In all we tagged and released about 13,000 sea scallops and recovered about 3,500 shells during the next 5 years. The growth data have been reported by Merrill et al. (1966) and the mortality data by Posgay (1963).

Sea scallops are vigorous swimmers and there have been persistent reports of beds of scallops "migrating," or at least moving away, to the distress of the fishermen. In an earlier paper (Posgay, 1963), I reported that of about 2,200 tagged scallops recovered during the first 2.5 years after release that 80 percent were reported less than 2 miles from the release point, 17 percent between 2 and 10 miles, and only 3 percent more than 10 miles. Many fishermen, however, still assert that sea scallops "migrate" and it was decided that a review of the release and recovery data was needed.

Methods

Tagging a sea scallop is a simple and rapid procedure. We fished them up in the same type of dredge used by the commercial fishermen (Posgay, 1957b) and immediately put them in a large tank of running seawater. All those with broken shells or other signs of damage were discarded.

The lower (right) valve has a deep byssal notch that is not present in the upper valve. We used a small drill press and a fine drill bit to bore a hole in the upper valve just over the byssal notch. A stainless steel pin with a circular numbered Petersen disc tag and a length of yellow plastic tape to increase visibility was then inserted in the hold and the pin bent over to secure it (Fig. 1) The animal is not injured in any way and soon puts down a layer of shell covering the pin and the hole. The entire procedure takes only a few seconds and the scallops are then returned to running seawater after the margin is nicked with a triangular file to permanently mark the size at the time of tagging. The disturbance caused by handling and tagging puts a "tagging check" on the shell. After several hundred had accumulated in the live well, they were carefully dip-netted out and returned to the sea. Records were kept of the number of scallops, the tag numbers, and the loran bearings of the release point (Table 1, Fig. 2)

Figure 1.—Recovered sea scallop shell showing tag and streamer. The nick put in the margin at the time of tagging can be seen on the left.

Fishery statistical agents in all the major ports of landing in the United States and Canada were informed of the tagging program and provided with posters offering rewards for the return of tagged scallops (Fig. 3) to be put up in favorable locations. Port agents were provided with funds so that they could pay the rewards immediately when a tagged shell was turned in. Press releases were distributed to give the program the widest possible publicity. Preprinted cards with spaces for the required recovery data were given to the port agents with instructions for their completion. The tagged shells and the cards with the recovery data were then sent to the laboratory, checked, and time at large and size at release and recapture were recorded.

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Table 1.—List of drop numbers, dates, locations, and number of tagged sea scallops released.

Drop no.	Date	No. released	Location
16	9/22/57	498	41°52'N 66°20'W
20	9/23/57	575	41°51'N 66°21'W
21	9/23/57	790	41°51'N 66°22'W
25	6/23/58	676	41°56'N 66°46'W
26	6/22/58	538	42°07'N 66°56'W
27	6/23/58	285	42°09'N 66°52'W
28	6/23/58	581	42°07'N 66°52'W
29	6/23/58	452	42°08'N 66°52'W
30	6/21/58	999	41°43'N 66°14'W
31	6/23/58	500	41°26'N 66°22'W
32	6/23/58	500	41°28'N 66°26'W
33	6/24/58	800	41°30'N 66°16'W
34	6/23/58	500	41°33'N 66°18'W
35	6/23/58	600	41°26'N 66°23'W
36	6/23/58	608	41°30'N 66°27'W

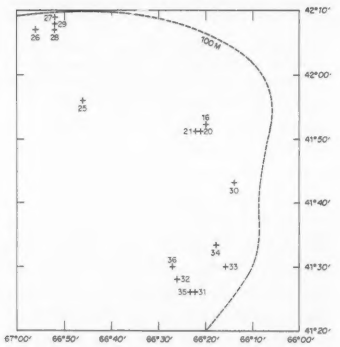

Figure 2.—Locations and drop numbers of the releases of tagged sea scallops on eastern Georges Bank.

Figure 3.—Reward poster publicizing the sea scallop tagging experiment.

The locations at which the groups of tagged scallops were released were all determined using the loran-A equipment on the research vessel and most of the recoveries also gave loran bearings for the locations of recapture. These kinds of data are not extremely precise. At best, with good equipment well maintained and operated, a loran fix is accurate to about ±0.25 mile (Haislip, 1962). This is probably a fair estimate of the release locations but the recovery locations are almost certainly much less accurate.

A single tow by a scalloper may cover 3-5 miles depending upon the skipper's estimates of the abundance. This may mean crossing the loran lines of position by as much as 50-60 microseconds depending on the area being fished. The fishing skippers are usually not particularly concerned about their exact location during a trip and very few keep records of the location of each tow. Therefore, the reported locations of capture are apt to be good only in a general sense. Inspection of the records shows some digit bias; locations are given as the intersection of two of the printed lines on the chart with few indications of any attempt at interpolation. In addition to these inherent sources of error, there are certainly instances of memory lapse and some cases of deliberate misinformation. Most fishermen don't like to tell anyone, let alone a government representative, just where they were fishing even if they have

been surrounded by a dozen other boats.

An aquarium experiment was conducted to determine if the tag and streamer affected the movement of the tagged scallops. The tank used was about 3 m wide by about 7 m long with the water about 1 m deep. Sea scallops used were all healthy and vigorous with a mean size of about 110 mm. Fifty were tagged, in the manner described above, and 50 left untagged. Both groups were placed in a windrow equidistant from the ends of the tank and left undisturbed for a week. When next examined, all of the scallops, tagged and untagged, were congregated at one end of the tank. During normal daytime activities around the experimental tank it was illuminated by overhead fluorescent lights which were nondirectional, but at night a single light some distance away was left on for the watchman. This seemed to be the only gradient so we put the scallops back in the center of the tank and covered it with a black plastic tarpaulin. A space was left open at one end and a small desk lamp left on over the opening. Once again, all the scallops moved toward the light. The position of the light was reversed and again the scallops moved towards it. A small ultraviolet lamp of the type used for examining geological specimens was substituted for the incadescent lamp with the same results. The scallops were put back in the center of the tank and the tank covered completely. Observations over the next few weeks (Fig. 4) showed that the scallops sorted themselves out more or less at random with no difference between those tagged and those untagged.

Figure 4.—Tagged and untagged sea scallops in experimental tank.

Results

The card files were purged of all records of scallops that showed that they had been dead for some time before recapture, those that had been recaptured less than 5 months after release, and those that had incomplete recapture information. The remaining 1,070 records were then placed on a computer tape and run through a program that converted the loran bearings to latitude and longitude and calculated the distance and direction of each reported recovery point from each release point. In the interest of brevity, only summaries of these data are given here; the complete data set can be found in the NEFC Laboratory Reference 80-28[1]. Table 2 gives the total number of tag returns separated into yearly intervals. Many of the tag returns came back in batches, more than one scallop turned in by the same vessel on the same trip. For the purposes of this paper, we have treated each of these multiple recaptures as a single data point. Tables 3-8 give the drop number, time at large in weeks, the distance and bearing of the reported recapture location from the point of release, and the number of scallops recovered from each location. These data were then plotted to show the distance and bearing of each recovery point from each release point without regard to actual geographic location (Fig. 5-8).

Table 2.—Number of recaptures by yearly intervals and percent returns by distance between release point and reported recapture point.

Time out (years)	Percent returns by distance 0-2 miles	2-5 miles	5-10 miles	>10 miles	No. of recaptures
<1	47.6%	33.3%	6.0%	13.1%	84
1-2	37.2	34.3	11.8	16.7	102
2-3	33.3	44.4	11.1	11.1	36
3-4	25.6	30.8	15.4	28.2	39
4-5	20.0	66.7	13.3	0	15
Total	37.3%	36.6%	10.5%	15.6%	276

About 17 of the 276 data points were located outside the frame of the charts used to plot Figures 5-8. These and all of the other points that were more than 10 miles from the release locations are given in Table 9.

Discussion

It is apparent from the tables and figures that most of the reported locations of recapture are fairly close to

[1]J. A. Posgay. 1980. Data report on the recoveries of tagged sea scallops from Georges Bank. NEFC Lab. Ref. 80-28.

Table 3.—List of tagged sea scallop recoveries with the distance and bearing of the reported location of recapture from the location of release (19.7-29.4 weeks at large).

Drop no.	Weeks out	Distance (n. mi.)	Bear.	No.	Drop no.	Weeks out	Distance (n. mi.)	Bear.	No.
16	19.7	1.5	170	11	28	24.0	1.2	143	2
20	19.7	7.1	323	3	28	24.4	1.6	175	2
21	20.0	0.4	234	44	30	24.4	9.1	335	2
16	20.0	2.2	235	8	21	24.7	0.9	223	4
20	20.0	1.1	257	10	30	24.8	7.4	006	1
30	20.1	5.0	195	4	28	25.3	3.7	143	1
29	20.3	1.2	131	7	28	25.3	4.9	163	1
21	20.3	3.3	355	8	28	25.3	0.8	294	17
26	20.7	3.3	186	1	28	25.3	2.1	313	1
20	21.0	1.1	118	13	25	25.6	10.7	024	1
21	22.7	0.9	357	4	25	25.6	1.2	081	1
30	23.0	0.9	004	1	25	25.6	3.3	337	2
21	23.0	2.0	151	33	25	26.0	1.3	257	12
16	23.0	2.8	191	15	25	26.1	1.8	131	6
21	23.0	0.2	343	45	25	27.1	0.9	288	4
28	23.4	1.8	143	2	16	29.0	2.7	303	1
28	23.4	1.9	155	1	21	29.0	2.6	342	4
29	23.4	2.7	156	1	26	29.3	0.3	039	3
25	23.6	0.9	288	21	26	29.3	3.4	145	2
28	23.7	1.6	175	7	26	29.4	1.6	043	3
25	23.7	4.3	277	1	26	29.4	1.4	120	2
25	23.7	0.8	300	9	29	29.4	2.4	226	1
25	23.9	0.6	194	1	26	29.4	1.5	329	34

Table 4.—List of tagged sea scallop recoveries with the distance and bearing of the reported location of recapture from the location of release (29.4-54.3 weeks at large).

Drop no.	Weeks out	Distance (n. mi.)	Bear.	No.	Drop no.	Weeks out	Distance (n. mi.)	Bear.	No.
26	29.4	0.8	335	1	28	48.1	23.1	103	1
30	29.6	10.8	339	11	30	48.1	3.2	327	1
30	29.6	1.9	355	1	36	49.0	17.2	032	1
26	30.1	3.4	145	2	30	49.0	1.5	344	3
16	30.1	1.6	170	1	36	49.4	2.6	013	2
26	30.6	4.7	145	3	20	49.6	0.8	143	21
26	30.7	14.7	137	1	33	50.6	16.4	006	5
25	30.7	2.6	331	2	34	50.6	13.6	013	9
30	31.7	1.4	013	1	30	50.6	12.5	112	1
30	31.7	1.9	355	31	34	50.7	0.5	188	3
30	32.6	1.4	013	1	34	50.7	1.0	200	4
30	32.6	1.7	016	21	33	50.7	2.7	285	1
30	32.6	2.9	352	3	33	50.7	3.0	328	5
30	32.7	1.9	355	1	33	50.8	17.6	344	7
26	34.1	19.6	098	3	34	51.6	0.8	167	4
16	37.1	2.4	186	6	30	52.1	9.7	216	1
25	37.4	5.7	291	1	34	52.1	3.5	307	2
21	44.7	3.6	124	5	34	52.4	2.7	199	2
20	44.7	3.0	132	3	30	53.4	35.9	312	2
16	44.7	3.4	153	1	36	53.7	3.0	324	7
35	45.1	11.9	008	2	20	54.0	1.2	138	1
30	45.4	7.2	245	1	20	54.3	1.4	161	6
26	47.4	4.7	178	2	20	54.3	2.2	182	1

Table 5.—List of tagged sea scallop recoveries with the distance and bearing of the reported location of recapture from the location of release (54.4-73.3 weeks at large).

Drop no.	Weeks out	Distance (n. mi.)	Bear.	No.	Drop no.	Weeks out	Distance (n. mi.)	Bear.	No.
25	54.4	1.1	171	7	26	61.0	1.5	161	2
30	55.9	0.9	004	1	16	61.3	1.0	267	2
34	55.9	10.4	014	1	26	62.2	9.0	144	1
30	55.9	0.5	274	6	26	63.1	8.4	144	4
33	56.0	11.8	019	1	20	63.4	1.6	080	1
25	56.0	17.8	095	1	16	63.4	1.1	133	20
30	56.0	1.1	302	21	16	64.4	5.5	107	6
25	56.5	1.1	171	3	21	64.4	1.0	136	20
20	56.6	1.4	161	3	16	64.4	1.9	204	2
28	57.0	12.2	076	1	16	64.7	18.7	282	1
21	57.1	3.5	013	1	20	65.3	1.4	161	10
16	57.1	2.5	344	4	16	65.3	2.4	186	4
26	57.3	4.9	086	1	21	65.3	5.2	326	6
26	58.0	4.7	124	1	16	66.0	26.6	294	2
16	58.1	2.1	323	1	21	66.0	25.7	298	1
26	58.2	4.7	124	6	20	66.3	1.4	161	2
25	58.2	1.1	171	6	21	67.3	3.7	360	3
20	58.4	2.9	181	12	16	67.3	3.0	331	3
20	58.7	1.4	161	3	20	67.7	0.6	070	1
30	59.4	12.4	335	11	21	68.3	8.8	327	4
26	60.1	1.5	161	11	20	71.4	8.6	138	8
26	60.4	28.0	130	2	16	71.4	8.9	146	2
20	60.7	2.9	181	13	21	73.3	1.0	109	3

Table 6.—List of tagged sea scallop recoveries with the distance and bearing of the reported location of recapture from the location of release (73.3-104.0 weeks at large).

Drop no.	Weeks out	Distance (n. mi.)	Bear.	No.	Drop no.	Weeks out	Distance (n. mi.)	Bear.	No.
16	73.3	1.4	200	9	16	93.0	13.5	183	2
30	77.8	30.8	299	1	21	94.4	1.8	107	1
20	78.0	1.1	118	1	21	94.4	6.8	115	1
16	78.0	1.6	170	3	21	94.4	6.8	119	1
25	80.6	1.1	171	2	21	94.4	4.9	139	2
25	80.8	1.8	193	3	16	94.4	1.6	170	1
25	80.8	3.6	301	1	21	95.0	26.3	306	4
25	81.3	1.1	171	1	21	95.9	2.1	118	3
20	83.0	13.1	187	3	21	95.9	2.5	121	2
25	83.0	3.6	315	2	16	95.9	3.6	126	4
25	83.4	3.6	301	1	21	95.9	2.5	132	4
28	85.4	11.8	265	1	16	95.9	2.1	170	8
25	89.0	4.6	350	2	16	95.9	1.6	170	5
20	90.0	6.0	047	2	16	95.9	2.7	172	5
20	90.0	4.2	192	1	16	95.9	4.7	305	3
21	90.0	0.9	223	1	21	95.9	4.4	327	1
26	91.1	3.8	105	1	20	95.9	1.7	334	3
26	91.3	5.2	104	1	26	96.7	10.2	264	1
21	92.3	1.8	107	2	21	97.0	2.5	132	1
20	92.3	1.1	118	1	20	97.0	2.0	146	2
16	92.3	1.6	170	1	21	99.3	1.8	138	3
26	92.5	0.9	091	1	26	100.3	2.8	146	1
21	93.0	12.5	177	8	21	104.0	4.0	174	1

the release points. Overall, 37 percent of the recaptures are within 2 miles of the release points, 74 percent are within 5 miles, and 85 percent are within 10 miles (Table 2). Many of the remaining 15 percent are somewhat suspect for one reason or another although we could find no objective grounds for disregarding them.

The direction of the apparent movement is interesting (Table 10). About 39 percent showed movement

Table 7.—List of tagged sea scallop recoveries with the distance and bearing of the reported location of recapture from the location of release (104.0-159.1 weeks at large).

Drop no.	Weeks out	Distance (n. mi.)	Bear.	No.	Drop no.	Weeks out	Distance (n. mi.)	Bear.	No.
21	104.0	3.7	178	3	25	129.4	3.7	329	1
16	104.0	4.9	196	1	25	130.0	4.1	193	1
26	105.1	2.2	158	1	35	130.2	3.2	207	1
16	106.8	27.9	307	2	21	130.8	1.5	099	6
36	108.4	2.8	294	5	16	130.8	1.0	194	9
25	112.1	3.6	315	1	28	135.2	1.9	148	1
25	112.3	4.6	209	1	25	137.7	3.5	163	1
25	113.0	3.6	315	2	36	138.0	3.0	254	1
36	113.0	33.1	329	1	28	138.2	7.4	077	1
36	113.3	0.5	330	14	36	141.5	3.0	254	4
36	117.4	1.4	230	1	35	141.8	10.2	345	2
30	121.1	0.3	108	2	36	144.4	2.2	324	2
30	125.5	0.5	274	1	29	152.0	8.3	205	1
16	127.4	2.9	054	7	20	153.2	2.4	105	3
21	127.4	4.7	055	6	20	155.5	1.4	161	1
29	127.7	2.5	127	7	26	157.6	3.5	152	1
36	128.0	1.4	247	3	25	157.6	24.4	276	1
28	128.2	6.0	132	2	32	158.4	3.6	147	1
29	128.2	6.7	141	10	16	158.5	11.3	321	1
21	128.7	1.8	085	1	32	158.6	3.1	020	1
29	128.7	1.9	135	4	30	158.7	17.9	206	1
16	128.7	1.0	194	2	30	159.0	0.9	004	1
28	129.0	12.5	118	1	32	159.1	3.1	020	2

Table 8.—List of tagged sea scallop recoveries with the distance and bearing of the reported location of recapture from the location of release (159.1-259.0 weeks at large).

Drop no.	Weeks out	Distance (n. mi.)	Bear.	No.	Drop no.	Weeks out	Distance (n. mi.)	Bear.	No.
21	159.1	9.9	322	1	34	205.1	2.3	177	1
35	159.4	0.6	189	3	34	205.3	19.8	209	1
32	159.7	3.2	130	1	31	205.3	12.2	212	1
35	159.9	0.2	117	1	31	205.3	1.7	322	1
32	159.9	3.2	130	1	33	205.9	0.8	348	1
20	160.4	9.8	145	1	25	206.0	1.1	171	1
20	160.8	16.8	304	1	32	208.0	8.6	189	1
34	165.1	1.6	264	1	31	208.0	0.8	357	1
34	165.7	2.4	099	1	32	208.2	2.6	060	2
35	168.9	2.5	348	1	36	208.7	3.5	357	4
28	169.0	34.7	116	3	36	208.9	10.0	251	1
28	172.9	15.1	165	2	36	208.9	3.0	284	1
33	174.7	2.6	329	1	36	209.6	2.6	013	1
32	175.1	1.4	318	1	36	209.6	4.5	021	1
35	176.6	2.1	297	1	36	209.6	2.8	229	3
28	180.9	0.4	026	1	35	209.6	5.6	292	1
28	182.1	2.1	359	1	32	210.6	2.6	102	1
32	186.6	7.6	192	1	35	210.6	3.6	296	1
25	188.6	16.4	294	1	31	211.4	1.0	236	1
27	193.0	7.7	169	1	36	225.0	2.9	314	1
32	197.4	47.7	321	1	36	252.0	1.2	303	1
35	202.4	9.7	211	1	34	259.0	0.8	167	3
31	202.4	10.1	215	1	33	259.0	2.6	329	1

Table 9.—List of tagged sea scallop recoveries that were reported recaptured more than 10 miles from the point of release.

Drop no.	Tag no.	Weeks out	Distance (n.mi.)	Bearing.	Drop no.	Tag no.	Weeks out	Distance (n. mi.)	Bearing
25	S4825	25.6	10.7	024	20	F4804+	83.0	13.1	187
30	S159+	29.6	10.8	339	28	F9975	85.4	11.7	265
26	F7163	30.7	14.7	137	21	F6264	93.0	12.5	177
26	F8486+	34.1	19.6	098	16	F3081	93.0	13.5	183
35	S4045+	45.1	11.9	008	21	F6083+	95.0	26.2	306
28	F9966	48.1	23.1	103	26	F7157	96.7	10.2	264
36	S4220	49.0	17.2	032	16	F3041+	106.8	27.9	307
33	S2498+	50.6	16.3	006	36	S4486	113.0	33.1	329
34	S3457+	50.6	13.6	013	28	F9314	129.0	12.5	118
30	E4961	50.6	12.5	112	35	S3554+	141.8	10.2	345
33	S2415+	50.8	17.5	344	25	D5757	157.6	24.4	276
30	S 643+	53.4	35.9	312	16	F3002	158.5	11.3	321
34	S3294	55.9	10.3	014	30	S 175	158.7	17.9	206
33	S2806	56.0	11.8	019	20	F4786	160.8	16.8	304
25	D5682	56.0	17.8	095	28	F9101+	169.0	34.7	116
28	F9361	57.0	12.1	076	28	F9274	172.9	15.1	165
30	E4900+	59.4	12.4	335	25	D5766	188.6	16.4	294
26	S 887+	60.4	28.0	130	32	S1684	197.4	47.6	321
16	F3144	64.7	18.7	282	31	S1208	202.4	10.1	215
16	F2714	66.0	26.6	294	34	S2000	205.3	19.8	209
21	F5656	66.0	25.7	298	31	S1090	205.3	12.2	212
30	S4842	77.8	30.8	299					

towards the southeast while about 30 percent went northwest. The tidal currents on eastern Georges Bank are rotary with the strongest vectors toward the southeast and northwest.

The data presented here and the inherent imprecision of the reported locations of recapture strongly suggest that adult sea scallops move very little if at all. We believe that the distance and direction that any individual sea scallop may swim at any given time is

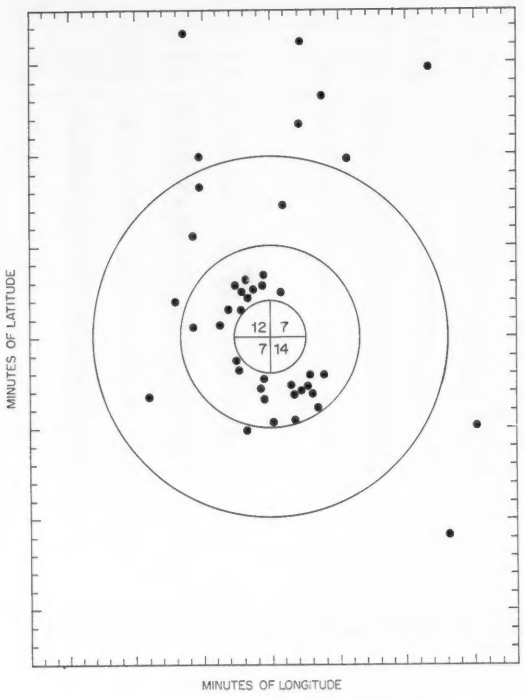

Figure 5.—Locations at which tagged sea scallops were reported recaptured during the first year after release relative to the location at which they were released. The figures inside the 2-mile circle give the number of recoveries in each quadrant.

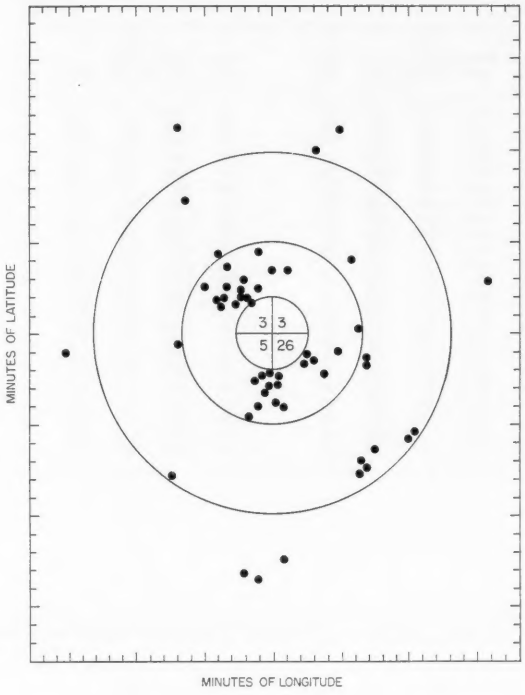

Figure 6.—Locations at which tagged sea scallops were reported recaptured during the second year after release relative to the location at which they were released. The figures inside the 2-mile circle give the number of recoveries in each quadrant.

Table 10.—Direction of movement of tagged sea scallops away from point of release by quadrant and years at large.

	Quadrant				
Years	001-090	091-180	181-270	271-360	001-360
<1	14	29	13	28	84
1-2	9	52	17	24	102
2-3	4	12	10	10	36
3-4	4	12	9	14	39
4-5	3	2	3	7	15
Totals	34	107	52	83	276

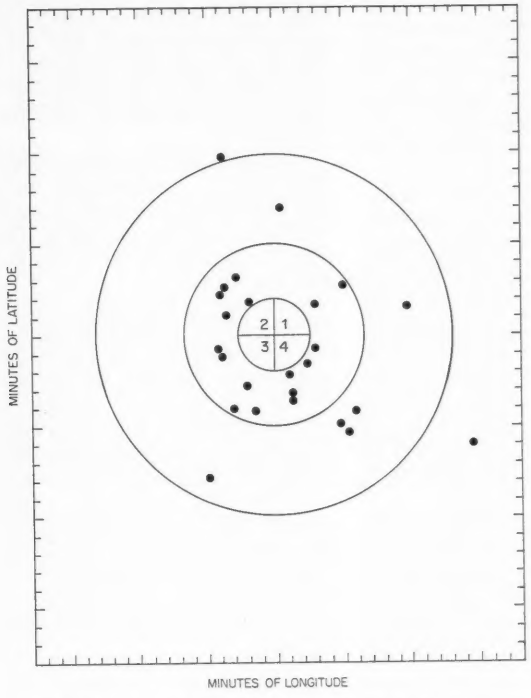

Figure 7.—Locations at which tagged sea scallops were reported recaptured during the third year after release relative to the location at which they were released. The figures inside the 2-mile circle give the number of recoveries in each quadrant.

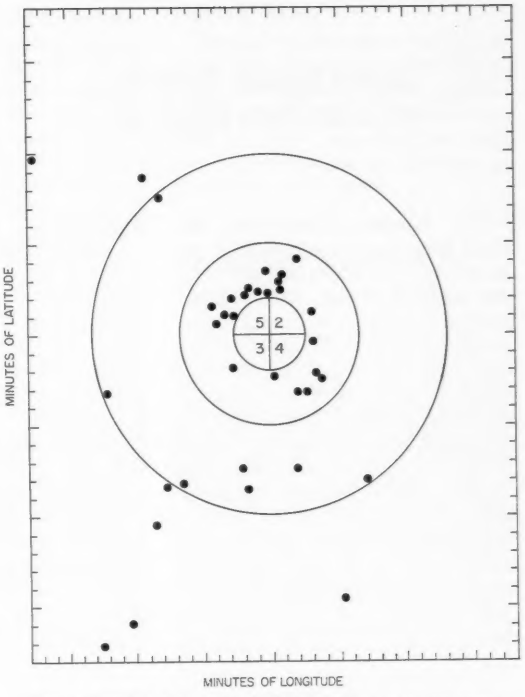

Figure 8.—Locations at which tagged sea scallops were reported recaptured during the fourth and fifth year after release relative to the location at which they were released. The figures inside the 2-mile circle give the number of recoveries in each quadrant.

probably random and that any net movement over time is probably the result of the strength and direction of the tidal currents.

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Japan Eases Stance on U.S. Fish Imports

The Japanese government has taken important steps to make it easier for the U.S. fishing industry to export seafood products to Japan, according to Richard A. Frank, former administrator of the National Oceanic and Atmospheric Administration (NOAA). Frank made the announcement after returning from Tokyo last December where he met with Japan Fisheries Agency officials and Japanese fishing industry representatives to review steps taken by Japan to implement a bilateral fisheries trade agreement. That agreement was negotiated in Washington, D.C., last July, pusuant to a U.S. policy that has become known as the "fish and chips" policy.

Under the policy, a country wishing to fish in the U.S. 200-mile Fisheries Conservation Zone must ease trade restrictions on U.S. fish imports in exchange for allocations of fish in U.S. waters. "Because the Japanese have fully implemented the terms of the July agreement," said Frank, "the opportunities available to exporters of U.S. fish products to Japan have never been better."

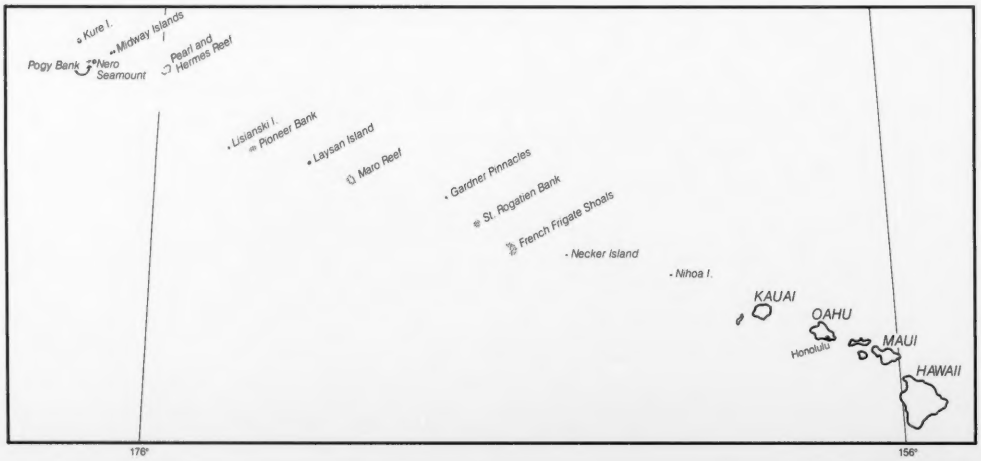
Among measures recently taken by Tokyo to implement the July accord are an increase in the Japanese import quota for herring and other fish, an increase in the number of Japanese organizations allowed to import fish products, the establishment of contact points in both countries to assure continuous communication on trade matters, and an agreement to provide to the United States with current information on the condition of Japanese markets.

Frank emphasized to the Japanese that the July accord must be more than a technical agreement. It must produce a significant increase in U.S. exports of seafood to Japan over the next year, he said.

Following his meetings in Tokyo, Frank met with officials of the Korean government in Seoul. The NOAA administrator informed the Koreans of the U.S. intent to increase its seafood exports to Korea, and discussed the U.S. policy of linking fish allocations to Korea with the easing of trade barriers by Seoul. Frank reported that the Koreans indicated their willingness to enter negotiations leading to a trade agreement similar to the U.S.-Japanese accord reached in July. These negotiations were to begin this year.

Hawaiian Research Cruise Nets Good Numbers of Fish

The NOAA ship *Townsend Cromwell* returned to Honolulu on 16 December after a 44-day cruise to waters around the Northwestern Hawaiian Islands (NWHI), and reported finding some fairly good concentrations of commercially valuable marine species. Cruise missions also included investigation of the Hawaiian monk seal, *Monachus schauinslandi,* status, at several islands in the chain and conducting a preliminary nearshore survey over reef flats at all island locations to determine the distribution of brown and red seaweeds on which the microscopic unicellular alga, *Gambierdiscus toxicus,* grows as an epiphyte. (This alga has been implicated as a source of the ciguatoxin in the coral reef ecosystem which eventually finds its way to the flesh



and organs of some commercially important fishes.) Other surveys assessed the lobster, shrimp, bottomfish, kona crab, pelagic, and benthopelagic fish resources throughout the NWHI.

According to Richard Shomura, Director of the NMFS Honolulu Laboratory, the *Townsend Cromwell* cruise was part of a cooperative long-term effort involving the Honolulu Laboratory, the State of Hawaii's Department of Land and Natural Resources, the U.S. Fish and Wildlife Service, and the University of Hawaii's Sea Grant Program to survey and assess the living terrestrial and marine resources in the NWHI.

A variety of fishing gear including lobster, fish, and shrimp traps; kona crab nets; hydraulically operated handlines; shrimp trawls; and trolling lines were used for the surveys. Catches made by the various gears indicated relatively good concentrations of commercially valuable species such as red snapper, *Etelis marshi;* opelu, *Decapterus macarellus;* and fair concentrations of caridean shrimps, *Heterocarpus ensifer* and *H. laevigatus.* The *Townsend Cromwell* also intensified efforts to locate fishing grounds for kona crab, *Ranina ranina,* during the cruise. According to Paul Shiota, chief scientist on the first leg of the cruise, previous cruises revealed the presence of kona crab over sandy bottoms at several locations in the NWHI. On the latest series of cruises, the Honolulu Laboratory scientists attempted to define the kona crab's distribution and relative abundance more precisely to evaluate its commercial potential. Night "jigging" for opelu and akule during the dark moon phases of the month was reported particularly effective at French Frigate Shoals.

After a brief layover at Midway Islands, the *Townsend Cromwell* visited several seamounts in the northwest end of the Hawaiian chain. Richard N. Uchida, chief scientist for the return leg of the cruise, reported excellent bottomfishing at Pogy Bank, one of the banks in the Nero Seamount complex, about 40 miles southwest of Midway. Here, the catch rate of bottomfish, mostly red snapper, *Etelis marshi,* and sea bass, *Epinephelus quernus,* reached 6.1 fish per line-hour. Because the entire Nero Seamount complex is poorly charted on existing maps, the *Townsend Cromwell* also made some transects with the echo sounder to better define the topography of the bank.

The return leg of the cruise also involved considerable effort to locate additional shrimp trapping ground of commercial potential. Concentrations of caridean shrimps were first discovered at Necker Island, Laysan Island, Pioneer Bank, and French Frigate Shoals in 1973 on a cruise of the RV *David Starr Jordan.* The *Townsend Cromwell's* shrimp trapping operations have revealed that caridean shrimps also occur in varying densities at Gardner Pinnacles, Maro Reef, and St. Rogatien Bank. According to Uchida, the catch rate, which was highest at Gardner Pinnacles, is only about a third of that obtained for trapping conducted off Oahu several years ago. Uchida estimated that about 27 percent of the *H. ensifer* and 56 percent of the *H. laevigatus* at Gardner Pinnacles were ovigerous or carrying eggs. Also, about 21 percent of the *H. ensifer* catch at Gardner Pinnacles consisted of cannibalized individuals. The highest rate of cannibalism occurred in traps with large catches and in which the bait supply was nearly exhausted.

Assisting cruise leaders Shiota and Uchida were Research Assistants Darryl T. Tagami, Victor A. Honda, Steven Kramer, Nathaniel Shippen, and Systems Analyst George Liao. Also included in the field party were William G. Gilmartin and Eric Knudtson, who were responsible for the studies on the monk seal, and Nancy Withers and Deborah Burns, who collected algae samples for their ciguatera research.

Howard Raymond Cited for Significant Paper

Howard L. Raymond of the NMFS Northwest and Alaska Fisheries Center, Seattle, Wash., received an award from the American Fisheries Society for the most significant paper in the 1979 issues (volume 108) of the *Transactions of the American Fisheries Society.*

The title of his paper is "Effects of Dams and Impoundments on Migrations of Juvenile Chinook Salmon and Steelhead from the Snake River, 1966 to 1975." Raymond has been working on fish-passage problems at the Center for 21 years.

Botulism Studied in Hatchery Fish Kills

Botulism was recognized as a major cause of juvenile salmon mortalities in the Pacific Northwest in 1979 when Mel Eklund and the botulism research group at the NMFS Northwest and Alaska Fisheries Center's Utilization Research Division identified type E *Clostridium botulinum* as the causative organism in the loss of over 1 million juvenile coho salmon at one Washington State hatchery.

In 1980, the research team conducted further studies in cooperation with the Washington State Department of Fisheries at the same hatchery earlier in the season. The disease was recognized in early stages last September when large numbers of the organism were found in the sediments and toxin was identified in the intestines of the juvenile salmon. The fish were moved to concrete-lined ponds and less than 20,000 salmon were lost. In October 1980 the Klaskanine Hatchery in Oregon lost 230,000 juvenile coho salmon. Eklund's group examined samples of the fish and pond bottom and confirmed the causative agent as type E botulism.

More recently, in response to queries about mortalities of juveniles at steelhead hatcheries, samples were taken for examination and botulism was identified as the cause of major mortalities in three different steelhead trout hatcheries. Research is currently in progress at the NWAFC using small-scale facilities for salmon and trout disease studies to determine methods for controlling the disease and minimizing botulism outbreaks in hatchery ponds.

Argentina Revises Marine Resources Forecast

The Argentine National Institute for Fisheries Research and Development (INIDEP) has revised its estimates of fishery stocks in Argentine waters. The new estimates are, in many cases, calculated from research data supplied by Japanese and German (FRG) scientists who cooperated with Argentine scientists during 1978 and 1979. Those research programs were negotiated as part of the agreements with German and Japanese consortia which allowed fishing companies in those two countries to fish experimentally. The research programs included over 1,500 test trawls by the RV *Walter Herwig* and the RV *Shinkzi Maru* from Argentina's marine frontier with Uruguay (lat. 35°S) to Argentina's extreme southern coast (lat. 55°S) (see map).

INIDEP has slightly reduced its previous estimate of the maximum sustainable yield (MSY) in Argentine waters from 2.7 million metric tons (t) to 2.4 million t, based on the results of the cooperative research programs (Table 1). The most significant changes were decreases in the MSY of hake, *Merluccius hubbsi,* and Antarctic blue whiting, *Micromesistius australis.*[1] The hake MSY was reduced by 100,000 t and is of particular significance as it is the major species caught by Argentine fishermen. Antarctic blue whiting is not yet caught in significant quantities. INIDEP did significantly increase its estimate of the MSY for squid from 38,000 t to 250,000 t. Catches by Argentina's joint ventures with Spain[2] have made squid one of the country's major fisheries.

[1]FAO refers to this species as southern poutassou.

[2]A report (No. DIB-80-04-007) describing the Argentine-Spanish joint venture can be purchased for $5.00 from NTIS, Springfield, VA 22161.

INIDEP indicated that three different systems were used by the Japanese, German, and Argentine scientists to calculate the MSY. According to INIDEP, the German system took into account yields from distinct depths, the Japanese system analyzed distinct stocks, while the Argentine system attempted to measure the abundance of each species. INIDEP reports that all three systems gave similar results with the Argentine estimate, usually within a range between the Japanese and German estimates.

The new INIDEP MSY estimates do not include krill, found in huge quantities in Antarctic waters but not yet successfully exploited commercially. Argentina signed a cooperative research agreement in 1980 with the Soviet Union to study Antarctic resources, especially krill. If results are successful, the Argentines foresee a possible joint venture with the Soviets to exploit that species.

INIDEP has acquired two new research vessels. The RV *Eduardo Holmberg* was due to arrive from Japan in September 1980 and the RV *Eolo* was to be available to INIDEP by late 1980.

One unexpected result of the cooperative research program is that Japanese fishing vessels have begun to

Table 1.—Statistical data on Argentina's major fishery stocks, 1980.

Species				MSY (1,000t)		
English name	Spanish name	Scientific name	Biomass	Old	New	Catch[1] (1979)
Anchovy	Anchoita	*Engraulis anchoita*	N/A[2]	1,000	1,000	20
Hake	Merluza	*Merluccius hubbsi*	3,927	698	594	404
Squid	Calamares	*Loligo* spp. and *Illex* spp.	510	38	250	80
Sharks and rays	Tiburones y rayas	Various species	942	26	150	12
Grenadiers	Granaderos	*Macruronus* spp.	540	46	97	
Blue whiting[3]	Polaca	*Micromesistius australis*	532	523	88	
Long-tailed hake	Merluze de cola	*Macroronus magellanicus*	424	161	76	
Antarctic cod	Bacalao austral	N/A	288	14	52	
Ling	Abadejo	*Genypterus blacodes*	246	27	44	
Native cod	Bacalao criollo	*Salilota australis*	N/A	13	36	
Notothenia	Nototenia	*Notothenia* spp.	92	19	17	
Black hake	Merluza negra	*Dissostichus eleginoides*	89	11	12	
Other				91	N/A[4]	114
Total			N/A	2,667	2,416	630

[1] Includes fish caught off Argentina by Uruguayan fishermen.
[2] N/A = Not available.
[3] FAO refers to this species as southern poutassou.
[4] For unexplained reasons, INIDEP did not include an MSY calculation for other species in the 1979 total.
Source: Instituto Nacional de Investigaciones y Desarrollo Pesquero (INIDEP).

fish squid off Argentina, outside the country's 200-mile zone. The Japanese consortia has not formed a joint venture in Argentina, probably because Argentina has insisted that the Japanese finance industrial projects in exchange for permission to form a joint venture. As a result, the Japanese fished for squid as a distant-water fishery in 1980 instead of operating out of Argentine ports. Argentine officials were concerned about this development and reported that 17 Japanese factory trawlers were fishing off Argentina last year. Earlier in 1980, Argentine officials reported a fleet of Polish vessels fishing off Argentina's 200-mile limit.

INIDEP has revised Argentina's development plans, based on the new findings and current economic problems encountered by Argentine fishermen and processing companies. INIDEP had originally projected a 1980 catch of 1 million t. The 1979 catch, however, was only about 550,000 t and INIDEP now doesn't believe 1 million t will be reached until 1982. INIDEP estimates that 2.4 million t of fish and shellfish (excluding krill) could be caught in Argentine waters. The largest single resource is a small anchovy, *Engraulis anchoita,* which INIDEP estimates has a MSY of 1 million t. INIDEP doesn't believe, however, that a significant commercial fishery on anchovy is possible because there is no demand for such a large quantity of that species. Thus, the development of the Argentine fishing industry has to be based on the remaining 1.4 million t which INIDEP estimates can be caught annually. (Source: IFR-80/138.)

Indonesian Fishing Industry Progresses

Indonesian fishermen reported a catch of 1.7 million metric tons (t) in 1978, a 9 percent increase over the 1977 catch. There has been a steady increase in Indonesia's fishery production for more than a decade and a concurrent climb in the quantity and value of exports.

Indonesia's 1978 exports totaled 64,000 t of fishery products valued at $190 million. Shrimp is the most important fisheries export product, and during the 1970's accounted for 85 percent of the quantity and 90 percent of the value of all fishery exports. Japan is Indonesia's largest customer for both shrimp and other fishery products taking about 85 percent of Indonesia's exports.

Shrimp is likely to continue to be Indonesia's most valuable export commodity; Indonesia's current five year plan (1979-1983) projects that exports of shrimp will increase from 32,600 t in 1978 to 35,200 t in 1983. Foreign participation in the shrimp fishery is generally closed, but participation is possible in other fisheries, notably tuna.

Elizabeth Bollman at the U.S. Embassy in Jakarta has prepared a 23-page report on Indonesian fishing developments during the 1970's. A copy of that report can be purchased for $5.00 by ordering report number DIB-80-05-004 from the National Technical Information Service, Springfield, VA 22161. (Source: IFR-80/146.)

Japan Fishing Company Aids Modernization of China's Fish Industry

Resource protection, increased fish breeding, and refrigeration improvements are reported to be the three main fishery policy components in China's drive to modernize its fishing industry. Still observers report that it may take 5-7 years for modernization to permeate the Chinese fishing industry.

Taiyo Fishing Company[1], a major Japanese fishing firm, sent a 7-member team to China last year to observe Shandong's Yantai Ocean Fishing Company, and other regional facilities, to assist China in modernizing their fishing industry. The team, headed by Managing Director K. Nakashima, studied Chinese management processes, fishing vessel construction, wharf facilities, and freezing equipment and processes.

In particular China's General Bureau of Aquatic Products Director Xiao Peng had requested aid in modernizing refrigeration techniques for the export of yellow sea shrimp, *Penaeus orientalis,* in the Bohai Gulf. The Bureau wants to set up the Yantai Ocean Fishing Company as a model for other fishing companies in China and intends to manage it directly. This company possesses 97 large dragnet vessels—40 with more than 400 horsepower (20 pairs) — and 10 purse seining vessels. It lands 450,000 tons of fish per year, has a 10,000-ton cold storage capacity, and operates netting factories and shipyards.

By assisting in the modernization program, Taiyo will reportedly receive orders for refrigeration and netting equipment and a China National Cereals, Oils, and Food Stuffs Importing and Exporting Corporation (CEROILS) center, to be established in Bohai with eight 50-ton prefabricated cold stores.

The Japanese group inspected fishing industries in Liaoning and Hebei provinces to study and encourage concrete modernization measures. They also observed Dairen's Liaoning Ocean Fishing Corporation and the Quingzhou Gulf, Zhimiao Gulf, and Qinghuangdao fishery-related facilities. The wharf and freezing equipment, and the treatment factories were considered far behind the preservation capabilities of Japan.

Some problems observed included lack of understanding of the procedure for handling the fish catch on board vessels and icing with excessively large ice particles, thus halving preservation capabilities.

From these observations, Taiyo made the following recommendations: 1) Introduce resource protection methods for yellow sea shrimp to increase reproduction; 2) teach

[1]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

methods of refrigeration, transportation, processing, and packaging; and 3) effectively prepare yellow sea shrimp, globe fish, angler fish, and squid for export.

China reportedly has good facilities and machines for domestic refrigeration, but needs additional technical skills in order to export fish. However, the understanding about the need for good refrigeration among fishing crews is limited and this must parallel modernization of the industry, according to the Japanese team. (Source: LSB 80-20.)

Brazil Promulgates New Marine Resource Policy

Brazilian President Joao Batista Figueiredo issued a new national marine resource policy in 1980 which appears to strengthen the role of the Interministerial Commission on Marine Resources (CIRM). The growing importance of CIRM as a key agency in determining marine resource policy was first apparent when a high ranking naval officer, Orlando Amaral Alfonso, was named CIRM's Executive Secretary.

Brazil's new national policy for marine resources aims to promote the integration of Brazilian-claimed waters, continental shelf, and space, and the rational exploitation of marine resources for the economic and social development of the country. The objectives of the new policy are:

1) Facilitate the development of education, research, and rational exploitation and exploration of Brazilian marine resources.

2) Stimulate the development of national technology and equipment.

3) Guarantee effective Brazilian participation in all phases of foreign research, exploration, and exploitation in Brazilian-claimed waters.

4) Bring Brazilian marine resource legislation up to date.

5) Improve the use and formation of Brazilian marine resource technical and scientific personnel at all levels.

6) Enhance the exchange of scientific and technical information, both internally and externally, related to training, research, exploration, and exploitation of marine resources.

7) Stimulate the creation of a national center of research and training dedicated to marine study.

8) Participate in regional exploitation of marine resources beyond national jurisdictions.

The Government of Brazil reserves for itself the exclusive right to direct, coordinate, and control research, exploration, and exploitation of living, mineral, or energy resources in Brazilian-claimed waters and on the continental shelf, including the respective ocean floor, subsoil, and the water column. The President, in consultation with the National Security Council, will determine national policies on marine resources as proposed and assisted by the Interministerial Commission for Marine Resources (CIRM). The Minister of the Navy will exercise the role of President of CIRM. Other members of CIRM will be representatives from Ministries of External Relations, Transportation, Agriculture, Education, Industry and Commerce, Mines and Energy, Interior, and the Planning Secretariat and the National Council for Scientific and Technological Development (CNPQ). Each of these agencies has specific responsibilities related to marine resources.

The CIRM, as direct adviser to the President, must: 1) Make policy recommendations to the President; 2) monitor the results of the national policy for marine resources and to propose alterations to the President when necessary; 3) provide opinions and suggestions related to marine resources when needed by the President; 4) evaluate the planning and the programs of activities concerning marine resources and make annual suggestions to the President on project priorities; and 5) establish contacts with the ministries not represented on the Commission and also with the state governments and private companies, and promote and support national marine resources plans and programs.
(Source: U.S. Embassy and IFR-80/158.)

NORWAY, RUSSIA OKAY FISHERY QUOTAS

Norway and the Soviet Union have reached agreement on proposed quotas for fisheries in the Norwegian and Soviet zones in 1981, the Norwegian Information Service reports. The proposed allocations are shown in the table below.

The parties agreed that 35,000 t of the quota for Arcto-Norwegian cod is to be allocated to a third country and 6,000 t of this amount is to be fished in the Svalbard zone. Of the remaining 29,000 t, 17,500 t is to be licensed off to a third country in the Norwegian zone and 11,500 t in the Soviet zone.

No progress was made in the negotiations on mesh width. This will be the subject of joint Soviet/Norwegian research, and the results will be submitted to a commission. As regards capelin fishing, the right to transfer landings from summer and autumn fisheries to winter fisheries will be maintained. It has also been stipulated that by 25 January the one party must have made a decision to transfer the winter capelin quota to the other party. This means that the Soviets can transfer part of the winter quota to Norway. In this connection a catch of 50,000 t was intimated from the Soviet side. Whether or not a third party will share in the quotas mentioned here, was to be the subject of negotiations with the respective countries.

Quotas of the most important types of fish in thousands of metric tons.

Fish	Total 1980	Total 1981	Norway	USSR	Other countries
Arcto-Norwegian cod	350	260	112.5	112.5	35
Norwegian coastal cod			40		
Murmansk cod				40	
Haddock	75	110	65	35	10
Redfish	100	89			
Redfish in Norw. E.Z.		71.5	28.5	47	
Winter capelin	1,000	1,200	720	480	
Summer capelin	700	700	420	280	
Blue whiting	100	150		150	

New NMFS Scientific and Technical Reports Published

Most of the publications listed here may be purchased from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402 (if listed as a sales item). Readers are advised to write that agency prior to ordering to determine price and availability. Prices may change and prepayment is required. Information on the availability of other NOAA publications can be obtained from the Environmental Science Information Center (D822), Environmental Data and Information Service, NOAA, 6009 Executive Boulevard, Rockville, MD 20852. When out of print, copies of the reports (either paper or microfiche) can be purchased from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22151.

NOAA Technical Report NMFS Circular 436. Uchida, Richard N. **"Synopsis of biological data on frigate tuna, *Auxis thazard,* and bullet tuna, *A. rochei.*"** January 1981.

Abstract

This circular contains biological and fisheries data on the frigate and bullet tunas from over 200 published and unpublished reports, up to and including those published in 1978. Information is presented on identity, distribution, bionomics, life history, population, and exploitation. (This report is also listed as FAO Fisheries Synopsis 124.)

NOAA Technical Memorandum NMFS F/SEC-17. Zuboy, J.R., and A. C. Jones. **"Everything you always wanted to know about MSY and OY (but were afraid to ask)."** June 1980. 19 p. (Available from the Southeast Fisheries Center, NMFS, NOAA, 75 Virginia Beach Drive, Miami, FL 33149.)

Abstract

The eight fishery management councils established by the Fishery Conservation and Management Act of 1976 are mandated to manage U.S. marine fisheries resources occurring in the fishery conservation zone based on the concepts of maximum sustainable yield and optimum yield. Fulfilling the mandate requires a thorough understanding of these concepts. It is the purpose of this paper to present a nontechnical discussion of maximum sustainable yield and optimum yield to facilitate understanding by the councils, which are composed largely of laypersons, so that they may carry out their duties under the Act.

A Basic Guide to Mussel Farming

With interest rising in mussel culture, the New Zealand Fishing Industry Board has published **"Mussel Cultivation in the Marlborough Sounds"** by Technical Officer R.J. Jenkins, whose main task for the past 8 years has been the development of mussel farming there.

Since 1972, mussel culture in the Marlborough Sounds has developed from the "idea stage" to the establishment of 50 marine farms, application for 150 more, and an annual production of 600-1,000 t of mussels. This volume is a record of that progress in research and development of mussel culture. As such, it constitutes a fine guide to mussel farming practices and provides a wealth of related information.

In New Zealand, the more widely available green-lipped mussel, *Perna canaliculus,* has been most harvested and cultured, although the blue mussel, *Mytilus edulis aoteanus,* a more southerly subspecies, is now being more readily exploited.

Taxonomy and anatomy and biology of the mussels are amply described and illustrated. Culture methods, also well illustrated, are detailed, including spatfall forecasting, settlement monitoring, larvae monitoring, hatchery seed production, etc. Seed catching procedures are listed, and seed handling and maintenance is discussed. Mussel culture problems (fouling organisms, diseases, and parasites) are described.

Mussel farming equipment and techniques are also explored and illustrated. Best conditions for mussel farming areas are listed.

Finally, the author outlines mussel production that can be expected, along with means of determining readiness for harvesting and harvesting techniques. A glossary is also included.

The hardbound, 75-page book, likely to be of great interest to mussel farmers far beyond New Zealand, is available only from the New Zealand Fishing Industry Board, Private Bag, Manners St. P.O., Wellington, New Zealand, for NZ $8.00 (surface mail cost to the United States is NZ $1.25; second class airmail fee is NZ $5.05.

A Symposium on the Living Coelacanth

The coelacanth, *Latimeria chalumnae,* a primitive species once believed extinct, may be as hard to catch as to define. **"The Biology and Physiology of the Living Coelacanth,"** edited by John E. McCosker and Michael D. Lagios, presents 11 papers from a AAAS symposium in June 1977 ranging widely from "My story of the first Coelacanth" by M. Courtenay-Latimer, to the species' natural history, its influence on African ichthyology, its anatomy and physiology, and its taxonomic classification.

McCosker, inferring the natural history of the living coelacanth, reports that it "behaves like a large, reef-associated piscivorous grouper." However, most of the papers attempt to pin down the systematics of *Latimeria*. Michael D. Lagios, "The coelacanth and the Chondrichthyes as sister groups" points out perceived relationships between the coelacanth and the sharks. Other papers rebut that view: "Coelacanths: Shark relatives or bony fishes?" by L. J. V. Compagno; "Ventral gill arch muscles and the phylogenetic relationships of *Latimeria*" by E. O. Wiley; "Mechanisms of osmoregulation in the coelacanth: Evolutionary implications" by R. W. Griffith and P. K. T. Pang; and "Chordate cytogenetic studies: An analysis of their phylogenetic implications with particular reference to fishes and the living Coelacanth" by G. Dingerkus. Additional papers discuss the species' mineralized tissue structures, ventricular and notochordal fluids, growth hormone studies, creatine kinase isozyme evolution, and amino acids and taurine in intracellular osmoregulation.

The 175-page softcover volume is available from the California Academy of Sciences, San Francisco, CA 94118 (Attn: "Coelacanth Volume") for $10.00, tax and postage included.

The Future of the Pacific Salmon

Publication of **"Pacific Salmon, Scenarios for the Future"** by Peter Larkin has been announced by the University of Washington in Seattle. The author, dean of the graduate school at the University of British Columbia, is an internationally known fisheries biologist. His appearance as the first of the Donald McKernan Lecturers at the University of Washington forms the basis for this thoughtful booklet.

The author begins with an overview of the probable state-of-the-art of salmon management in the year 2020 and forecasts various aspects for long-range environmental predictions, better techniques of racial identification, possibilities in genetic engineering, and improved facilities for salmon hatcheries and aquacultural pursuits.

Next, he presents scenarios about the conduct of both commercial and sport fishermen of the 21st century, the altered roles of politicians and resource management agencies in 2020, and future social attitudes toward salmon harvesting. Finally, he predicts that the next two decades "will be characterized by new and exciting investigations that will bring our knowledge of Pacific salmon and of the North Pacific Ocean to levels of understanding that would be enriching to all mankind." The 23-page essay (WSG 80-3) is available at $3.00 per copy from the University of Washington, Washington Sea Grant, 3716 Brooklyn Ave. N.E., Seattle, WA 98105.

Handling Methods and Quality of Fresh Squid

"Handling Methods and Quality Evaluation of Fresh Canadian Atlantic Squid," Technical Report 898, has been published by Canada's Fisheries and Oceans Department. A physical quality examination of *Illex illecebrosus* based on skin color, texture, mantle condition, and odor has been developed and described for routine quality grading in the field. An organoleptic test procedure is also presented. Simplified guidelines for a three-grade system based on each procedure have reportedly been applied satisfactorily in various squid studies.

Using the proposed guidelines, the keeping times of squid using various handling methods and chilled seawater (CSW) and noncontact icing (NCI), have been estimated. NCI can preserve squid quality slightly better than CSW storage. A modified NCI method, with some seawater added, gave the longest squid keeping time. Both NCI and CSW, with various containers, can be used for holding squid for at least 2 days with excellent quality and skin color, and for more than 3 days with acceptable quality. The report is available from the Research Section, Inspection Division, Field Services Branch, Fisheries and Oceans, P.O. Box 550, Halifax, Nova Scotia, Canada B3J 2S7.

FAO, UNESCO Fisheries Publications Available

The availability of several FAO fisheries publications has been announced by UNIPUB, 345 Park Ave. South, New York, NY 10010. Among them are the following items.

Two additional FAO Fisheries Synopses have been published: No. 120, **Synopsis of Biological Data on the Mrigal, *Cirrhinus mrigala* (Hamilton, 1822)"** by V. G. Jhingran and H. A. Khan of the Central Inland Fisheries Research in West Bengal, India; and, No. 125, Vol. 1, an FAO Species Catalog, **"Shrimps and Prawns of the World, An Annotated Catalogue of Species of Interest to Fisheries,"** by L. B. Holthuis of the Rijksmusium van Natuurlijke Historie, Leiden, The Netherlands. It includes all species known to the author to be used for human consumption, sold for bait and as subproducts, and species not commercially caught, but considered by experts to be of potential commercial value. This 271-page synopsis costs $15.50; No. 120, 78 pages, costs $7.50.

Other FAO volumes available include **"World List of Aquatic Sciences and Fisheries Serial Titles"** (FAO Fish. Tech. Pap. 147, Supplement 4) ($7.00), which provides data on another 429 titles since the supplement in 1978; **"Evaluation of the Fishery Resources of the Eastern Central Atlantic"** (FAO Fish. Rep. 220; $11.00), a report of the fourth session of the Working Party on Resource Evaluation of the Fishery Committee for the Eastern Central Atlantic (CECAF); and CIFA Tech. Pap. 6, **"Role of Fishery Technology in the Management and Development of Freshwater Fisheries in Africa."** This 67-page booklet costs $7.50.

Editorial Guidelines for *Marine Fisheries Review*

Marine Fisheries Review publishes review articles, original research reports, significant progress reports, technical notes, and news articles on fisheries science, engineering, and economics, commercial and recreational fisheries, marine mammal studies, aquaculture, and U.S. and foreign fisheries developments. Emphasis, however, is on in-depth review articles and practical or applied aspects of marine fisheries rather than pure research.

Preferred paper length ranges from 4 to 12 printed pages (about 10-40 manuscript pages), although shorter and longer papers are sometimes accepted. Papers are normally printed within 4-6 months of acceptance. Publication is hastened when manuscripts conform to the following recommended guidelines.

The Manuscript

Submission of a manuscript to *Marine Fisheries Review* implies that the manuscript is the author's own work, has not been submitted for publication elsewhere, and is ready for publication as submitted. Commerce Department personnel should submit papers under completed NOAA Form 25-700.

Manuscripts must be typed (double-spaced) on high-quality white bond paper and submitted with two duplicate (but not carbon) copies. The complete manuscript normally includes a title page, a short abstract (if needed), text, literature citations, tables, figure legends, footnotes, and the figures. The title page should carry the title and the name, department, institution or other affiliation, and complete address (plus current address if different) of the author(s). Manuscript pages should be numbered and have 1½-inch margins on all sides. Running heads are not used. An "Acknowledgments" section, if needed, may be placed at the end of the text. Use of appendices is discouraged.

Abstract and Headings

Keep titles, heading, subheadings, and the abstract short and clear. Abstracts should be short (one-half page or less) and double-spaced. Paper titles should be no longer than 60 characters; a four- to five-word (40 to 45 characters) title is ideal. Use heads sparingly, if at all. Heads should contain only 2-5 words; do not stack heads of different sizes.

Style

In style, *Marine Fisheries Review* follows the "U.S. Government Printing Office Style Manual." Fish names follow the American Fisheries Society's Special Publication No. 6, "A List of Common and Scientific Names of Fishes from the United States and Canada," third edition, 1970. The "Merriam-Webster Third New International Dictionary" is used as the authority for correct spelling and word division. Only journal titles and scientific names (genera and species) should be italicized (underscored). Dates should be written as 3 November 1976. In text, literature is cited as Lynn and Reid (1968) or as (Lynn and Reid, 1968). Common abbreviations and symbols such as mm, m, g, ml, mg, and °C (without periods) may be used with numerals. Measurements are preferred in metric units; other equivalent units (i.e., fathoms, °F) may also be listed in parentheses.

Tables and Footnotes

Tables and footnotes should be typed separately and double-spaced. Tables should be numbered and referenced in text. Table headings and format should be consistent; do not use vertical rules.

Literature Citations

Title the list of references "Literature Citations" and include only published works or those actually in press. Citations must contain the complete title of the work, inclusive pagination, full journal title, the year and month and volume and issue numbers of the publication. Unpublished reports or manuscripts and personal communications must be footnoted. Include the title, author, pagination of the manuscript or report, and the address where it is on file. For personal communications, list the name, affiliation, and address of the communicator.

Citations should be double-spaced and listed alphabetically by the senior author's surname and initials. Co-authors should be listed by initials and surname. Where two or more citations have the same author(s), list them chronologically; where both author and year match on two or more, use lowercase alphabet to distinguish them (1969a, 1969b, 1969c, etc.).

Authors must double-check all literature cited; they alone are responsible for its accuracy.

Figures

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